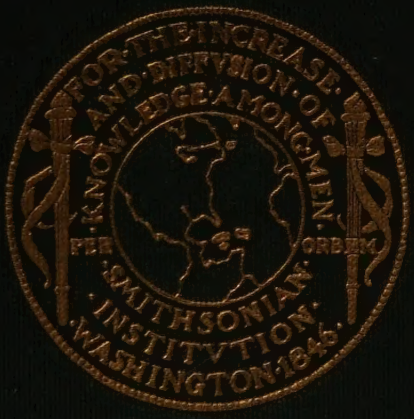
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ANNUAL REPORT OF THE BOARD OF REGENTS OF

THE SMITHSONIAN INSTITUTION

SHOWING THE OPERATIONS, EXPENDITURES AND CONDITION OF THE INSTITUTION FOR THE YEAR ENDING JUNE 30

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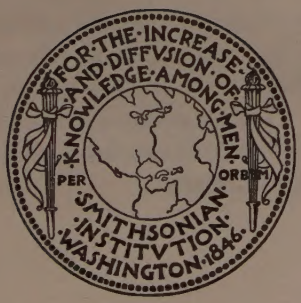

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LETTER

FROM THE

SECRETARY OF THE SMITHSONIAN INSTITUTION,

SUBMITTING

THE ANNUAL REPORT OF THE BOARD OF REGENTS OF THE INSTITUTION FOR THE YEAR ENDING JUNE 30, 1910.

SMITHSONIAN INSTITUTION,
Washington, May 29, 1911.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ending June 30, 1910. I have the honor to be,

Very respectfully, your obedient servant,

CHARLES D. WALCOTT, *Secretary.*

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ANNUAL REPORT OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDING JUNE 30, 1910.

SUBJECTS.

1. Annual report of the secretary, giving an account of the operations and condition of the Institution for the year ending June 30, 1910, with statistics of exchanges, etc.

2. Report of the executive committee, exhibiting the financial affairs of the Institution, including a statement of the Smithsonian fund, and receipts and expenditures for the year ending June 30, 1910.

3. Procedings of the Board of Regents for the sessions of December 14, 1909, and February 10, 1910.

4. General appendix, comprising a selection of miscellaneous memoirs of interest to collaborators and correspondents of the Institution, teachers, and others engaged in the promotion of knowledge. These memoirs relate chiefly to the calendar year 1910.

97578°—SM 1910——1

THE SMITHSONIAN INSTITUTION.

JUNE 30, 1910.

Presiding officer ex officio.—WILLIAM H. TAFT, President of the United States.
Chancellor.—MELVILLE W. FULLER, Chief Justice of the United States.
Members of the Institution:

WILLIAM H. TAFT, President of the United States.
JAMES S. SHERMAN, Vice President of the United States.
MELVILLE W. FULLER, Chief Justice of the United States.
PHILANDER C. KNOX, Secretary of State.
FRANKLIN MACVEAGH, Secretary of the Treasury.
JACOB M. DICKINSON, Secretary of War.
GEORGE W. WICKERSHAM, Attorney General.
FRANK H. HITCHCOCK, Postmaster General.
GEORGE VON L. MEYER, Secretary of the Navy.
RICHARD A. BALLINGER, Secretary of the Interior.
JAMES WILSON, Secretary of Agriculture.
CHARLES NAGEL, Secretary of Commerce and Labor.

Regents of the Institution:

MELVILLE W. FULLER, Chief Justice of the United States, Chancellor.
JAMES S. SHERMAN, Vice President of the United States.
SHELBY M. CULLOM, Member of the Senate.
HENRY CABOT LODGE, Member of the Senate.
AUGUSTUS O. BACON, Member of the Senate.
JOHN DALZELL, Member of the House of Representatives.
JAMES R. MANN, Member of the House of Representatives.
WILLIAM M. HOWARD, Member of the House of Representatives.
JAMES B. ANGELL, citizen of Michigan.
ANDREW D. WHITE, citizen of New York.
JOHN B. HENDERSON, citizen of Washington, D. C.
ALEXANDER GRAHAM BELL, citizen of Washington, D. C.
GEORGE GRAY, citizen of Delaware.
CHARLES F. CHOATE, JR., citizen of Massachusetts.

Executive Committee.—J. B. HENDERSON, ALEXANDER GRAHAM BELL, JOHN DALZELL.
Secretary of the Institution.—CHARLES D. WALCOTT.
Assistant Secretary.—RICHARD RATHBUN.
Chief Clerk.—HARRY W. DORSEY.
Accountant and Disbursing Agent.—W. I. ADAMS.
Editor.—A. HOWARD CLARK.

THE NATIONAL MUSEUM.

Assistant Secretary in charge.—RICHARD RATHBUN.
Administrative Assistant.—W. DE C. RAVENEL.
Head Curators.—WILLIAM H. HOLMES, F. W. TRUE, G. P. MERRILL.
Curators.—R. S. BASSLER, A. HOWARD CLARK, F. W. CLARKE, F. V. COVILLE, W. H. DALL, B. W. EVERMANN, J. M. FLINT, U. S. N. (retired), W. H. HOLMES, WALTER HOUGH, L. O. HOWARD, ALÉS HRDLIČKA, GERRIT S. MILLER, Jr., RICHARD RATHBUN, ROBERT RIDGWAY, LEONHARD STEJNEGER, CHARLES D. WALCOTT.
Associate Curators.—J. N. ROSE, DAVID WHITE.
Curator, National Gallery of Art.—W. H. HOLMES.
Chief of Correspondence and Documents.—RANDOLPH I. GEARE.
Superintendent of Construction and Labor.—J. S. GOLDSMITH.
Editor.—MARCUS BENJAMIN.
Photographer.—T. W. SMILLIE.
Registrar.—S. C. BROWN.

BUREAU OF AMERICAN ETHNOLOGY.

Ethnologist in charge.—F. W. HODGE.
Ethnologists.—J. WALTER FEWKES, J. N. B. HEWITT, FRANCIS LA FLESCHE, TRUMAN MICHELSON, JAMES MOONEY, PAUL RADIN, MATILDA COXE STEVENSON, JOHN R. SWANTON.
Philologist.—FRANZ BOAS.
Editor.—JOSEPH G. GURLEY.
Illustrator.—DE LANCEY W. GILL.

INTERNATIONAL EXCHANGES.

Chief Clerk.—C. W. SHOEMAKER.

NATIONAL ZOOLOGICAL PARK.

Superintendent.—FRANK BAKER.
Assistant Superintendent.—A. B. BAKER.

ASTROPHYSICAL OBSERVATORY.

Director.—C. G. ABBOT.
Aid.—F. E. FOWLE, Jr.

REGIONAL BUREAU FOR THE UNITED STATES, INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE.

Assistant in Charge.—L. C. GUNNELL.

REPORT

OF THE

SECRETARY OF THE SMITHSONIAN INSTITUTION

CHARLES D. WALCOTT,

FOR THE YEAR ENDING JUNE 30, 1910.

To the Board of Regents of the Smithsonian Institution:

GENTLEMEN: I have the honor to submit a report showing the operations of the Institution during the year ending June 30, 1910, including the work placed under its direction by Congress in the United States National Museum, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, the Astrophysical Observatory, and the regional bureau of the International Catalogue of Scientific Literature.

In the body of this report there is given a general account of the affairs of the Institution, while the appendix presents more detailed statements by those in direct charge of the different branches of the work. Independently of this the operations of the National Museum and of the Bureau of American Ethnology are fully treated in separate volumes.

THE SMITHSONIAN INSTITUTION.

THE ESTABLISHMENT.

By act of Congress approved August 10, 1846, the Smithsonian Institution was created an establishment. Its statutory members are "the President, the Vice-President, the Chief Justice, and the heads of the executive departments."

THE BOARD OF REGENTS.

The Board of Regents consists of the Vice-President and the Chief Justice of the United States as ex officio members, three members of the Senate, three Members of the House of Representatives, and six citizens, "two of whom shall be resident in the city of Washington, and the other four shall be inhabitants of some State, but no two of them of the same State."

There has been no change in the personnel of the Board since my last report, Representatives John Dalzell, James R. Mann, and William M. Howard; and Hon. John B. Henderson, and Dr. Alexander Graham Bell, whose terms of office expired during the year, having been reappointed as Regents.

Meetings of the Regents were held on December 14, 1909, and on February 10, 1910, the proceedings of which will be printed as customary in the annual report of the Board to Congress.

Although occurring a few days after the close of the fiscal year, I may properly record here the death on July 4, 1910, of the Chancellor of the Institution, Melville W. Fuller, Chief Justice of the United States. Adequate reference to this sad event will be made in my next report to the Board.

GENERAL CONSIDERATIONS.

I have called attention heretofore to the influence that the Smithsonian Institution has had in the development of science in this country. That its usefulness is not restricted to this country is constantly evidenced in many ways. But the achievements that the Institution might accomplish, and that the scientific world expects of it, and the general good that it might do in the promotion of the welfare of the human race, continues to be greatly limited by the lack of ample funds to carry forward worthy lines of exploration and research that are constantly being presented for consideration.

During the past year the Institution's activities have been increased to some degree by gifts for the promotion of certain special lines of study, particularly in biological research.

Among the important works that might be undertaken I would especially call attention to the great advantage to this country and to the world that would result from the establishment of a national seismological laboratory under the direction of the Smithsonian Institution.

IMPORTANCE OF A NATIONAL SEISMOLOGICAL LABORATORY.

NEED.

The immense destruction of life and property by certain large earthquakes emphasizes the importance of investigations which may lead to a reduction of the damage of future earthquakes. The science of seismology is in its infancy and it is not always evident what lines of investigation will yield the most important results, hence the importance of developing larger knowledge of seismology in all directions. As an example: It was not at all realized that the accurate surveys of the Coast and Geodetic Survey in California would demonstrate that the great earthquake there in 1906 was due to forces set up by slow movements of the land which have probably been going

on for a hundred years. We have learned that slow movements of the land must precede many large earthquakes, and monuments are now being set up in California to enable us to discover future movements of the land and thus to anticipate future earthquakes. This, I think, is the most important step so far taken toward the prediction of earthquakes.

COOPERATION.

Seismological work is too large to be prosecuted successfully by the universities, but requires some central office under government supervision to encourage theoretical and observational studies and to collect and study information from all available sources. The various departments of the Government could offer material help. The Weather Bureau could furnish information regarding felt shocks and could maintain seismographs at some of their stations. Postmasters throughout the country could also report felt earthquakes. The Coast and Geodetic Survey could maintain instruments and adapt their surveys and tidal observations to the detection of slow earth movements. The army could give information regarding earthquakes felt at their outlying posts, the navy regarding earthquakes felt at sea. The Geological Survey could furnish information regarding the geological structure of earthquake regions.

SEISMOLOGICAL CLEARING HOUSE AND FOREIGN COOPERATION.

The seismological laboratory would collect and study all this information. It would serve as a clearing house for the whole country. It would also be the link to connect seismological work in this country with the work done in other parts of the world. Its director should represent the United States in the International Seismological Association which this country has joined through the Department of State.

GOVERNMENT WORK IN FOREIGN COUNTRIES.

Germany, Italy, Hungary, Roumania, Bulgaria, and Japan have maintained for some years offices for the collection and study of earthquake material. Chile and Mexico have recently established them. The work in England is under the direction of the Royal Society. Many other countries maintain stations for seismological observations. This is the only important country subject to destructive earthquakes whose government does not support the study of earthquakes.

WORK OF THE LABORATORY.

1. Collection and study of all information regarding earthquakes in the United States and its possessions. The preparation of maps showing the distribution of earthquakes and their relation to geological structure.

2. The study of special regions which are subject to frequent earthquakes to determine as far as possible where future earthquakes are likely to occur.

3. The study of the origins of earthquakes occurring under the neighboring oceans.

4. An organization of commissions to study in the field the effects produced by large earthquakes.

5. The study of proper methods of building in regions subject to earthquakes. This will require experiment.

6. The improvement of instruments for recording earthquakes.

7. Other theoretical studies.

8. The dissemination of information regarding earthquakes by bulletins or otherwise.

EQUIPMENT.

There will be required an office, a laboratory, a photographic room, a work shop, and a special instrument house. The building of this latter house and the general equipment would cost about $6,000.

ORGANIZATION AND ANNUAL EXPENSES.

In the beginning there would be required a director, an assistant, a mechanic, a stenographer, and it would be necessary to purchase books, instruments, and material for the laboratory, etc. It is estimated that $20,000 would equip the laboratory and meet all the expenses for the first year. After that the work will probably expand and the amount applied to equipment for the first year would meet the requirements for extension for some time after.

FINANCES.

The permanent fund of the Institution and the sources from which it was derived are as follows:

Deposited in the Treasury of the United States.

Bequest of Smithson, 1846		$515,169.00
Residuary legacy of Smithson, 1867		26,210.63
Deposit from savings of income, 1867		108,620.37
Bequest of James Hamilton, 1875	$1,000.00	
Accumulated interest on Hamilton fund, 1895	1,000.00	
		2,000.00
Bequest of Simeon Habel, 1880		500.00
Deposit from proceeds of sale of bonds, 1881		51,500.00
Gift of Thomas G. Hodgkins, 1891		200,000.00
Part of residuary legacy of Thomas G. Hodgkins, 1894		8,000.00
Deposit from savings of income, 1903		25,000.00
Residuary legacy of Thomas G. Hodgkins		7,918.69
Total amount of fund in the United States Treasury		944,918.69
Registered and guaranteed bonds of the West Shore Railroad Company (par value), part of legacy of Thomas G. Hodgkins		42,000.00
Total permanent fund		986,918.69

The sum of $251.95 was received during the year as the first payment of a bequest of $500 made by the will of Mr. William Jones Rhees, for many years an officer of the Institution. This fund has not been invested.

In addition to the above there are four pieces of real estate bequeathed to the Institution by the late R. S. Avery, some of which yield a nominal rental and all are free from taxation.

That part of the fund deposited in the Treasury of the United States bears interest at 6 per cent per annum, under the provisions of the act organizing the Institution and an act of Congress approved March 12, 1894. The rate of interest on the West Shore Railroad bonds is 4 per cent per annum.

The income of the Institution during the year, amounting to $107,483.68, was derived as follows:

Interest on the permanent Foundation, $58,375.12; contributions from various sources for specific purposes, $43,230.95, and from other miscellaneous sources, $5,877.61; all of which was deposited in the Treasury of the United States to the credit of the current account of the Institution.

With the balance of $32,176.70, on July 1, 1909, the total resources for the fiscal year amounted to $139,660.38. The disbursements, which are given in detail in the annual report of the executive committee, amounted to $104,295.50, leaving a balance of $35,364.88 on deposit June 30, 1910, in the United States Treasury.

The Institution was charged by Congress with the disbursement of the following appropriations for the year ending June 30, 1910:

International Exchanges	$32,000
American Ethnology	43,000
Astrophysical Observatory	13,000
National Museum:	
Furniture and fixtures	200,000
Heating and lighting	60,000
Preservation of collections	250,000
Books	2,000
Postage	500
Building repairs	15,000
Moving collections to new building	4,000
National Zoological Park	95,000
International Catalogue of Scientific Literature	6,000
Total	720,500

EXPLORATIONS AND RESEARCHES.

As far as the resources of the Institution and contributions from individuals has permitted, various scientific explorations and researches have been carried on during the past year, and it is gratifying to report that the Institution's activities in these lines have been

somewhat more extended than in previous years. Were ample funds available to be administered under the Smithsonian Institution, the scientific work of the Government might often be supplemented by original researches of a character that could hardly be undertaken by the Government, and which would be of great service to humanity and to science.

Besides operations undertaken by the Institution itself, important biological, ethnological, and astrophysical researches have been carried on under its direction through the National Museum, the Bureau of American Ethnology, and the Astrophysical Observatory, which are discussed elsewhere in this report.

SMITHSONIAN AFRICAN EXPEDITION.

In my last report there was given an account of the setting out of the expedition to Africa in charge of Col. Theodore Roosevelt and of the results accomplished prior to June 30, 1909. This expedition, which was entirely financed from private sources through contributions by friends of the Smithsonian Institution, landed at Mombasa on April 21, 1909, and arrived at Khartoum on March 14, 1910. The collections made by it reached Washington in excellent condition and are now deposited in the National Museum. The series of large and small mammals from East Africa is, collectively, probably more valuable than is to be found in any other museum of the world. The series of birds, reptiles, and plants are also of great importance, and the study of the material representing other groups will furnish interesting results.

Colonel Roosevelt's report on the work of the expedition is as follows:

KHARTOUM, *March 15, 1910.*

SIR: I have the honor to report that the Smithsonian African expedition, which was intrusted to my charge, has now completed its work. Full reports will be made later by the three naturalists, Messrs. Mearns, Heller, and Loring. I send this preliminary statement to summarize what has been done; the figures given are substantially accurate, but they may have to be changed slightly in the final reports.

We landed in Mombasa on April 21, 1909, and reached Khartoum on March 14, 1910. On landing, we were joined by Messrs. R. J. Cuninghame and Leslie J. Tarlton; the former was with us throughout our entire trip, the latter until we left East Africa, and both worked as zealously and efficiently for the success of the expedition as any other member thereof.

We spent eight months in British East Africa. We collected carefully in various portions of the Athi and Kapiti plains, in the Sotik and around Lake Naivasha. Messrs. Mearns and Loring made a thorough biological survey of Mount Kenia, while the rest of the party skirted its western base, went to and up the Guaso Nyero and later visited the Uasin Gisbu region and both sides of the Rift Valley. Messrs. Kermit Roosevelt and Tarlton went to the Leikipia Plateau and Lake Hannington, and Doctor Mearns and Kermit Roosevelt made

separate trips to the coast region near Mombasa. On December 19 the expedition left East Africa, crossed Uganda and went down the White Nile.

North of Wadelai we stopped and spent over three weeks in the Lado, and from Gondokoro Kermit Roosevelt and I again crossed into the Lado, spending eight or ten days in the neighborhood of Rejaf. In Gondokoro we were met by the steamer which the Sirdar, with great courtesy, had put at our disposal. On the way to Khartoum we made collections in Lake No, and on the Bahr-el-Ghazal and Barel-Zeraf. We owe our warmest thanks for the generous courtesy shown us and the aid freely given us, not only by the Sirdar, but by all the British officials in East Africa, Uganda, and the Sudan, and by the Belgian officials in the Lado; and this, of course, means that we are also indebted to the home governments of Egypt and Belgium.

On the trip Mr. Heller has prepared 1,020 specimens of mammals, the majority of large sizes; Mr. Loring has prepared 3,163, and Doctor Mearns, 714, a total of 4,897 mammals. Of birds, Doctor Mearns has prepared nearly 3,100; Mr. Loring, 899; and Mr. Heller about 50, a total of about 4,000 birds.

Of reptiles and batrachians, Messrs. Mearns, Loring, and Heller collected about 2,000.

Of fishes, about 500 were collected. Doctor Mearns collected marine fishes near Mombasa and fresh-water fishes elsewhere in British East Africa, and he and Cuninghame collected fishes in the White Nile. This makes in all of vertebrates: Mammals, 4,897; birds, about 4,000; reptiles and batrachians, about 2,000; fishes, about 500; total 11,397.

The invertebrates were collected carefully by Doctor Mearns, with some assistance from Messrs. Cuninghame and Kermit Roosevelt. A few marine shells were collected near Mombasa, and land and fresh-water shells throughout the regions visited, as well as crabs, beetles, millipeda, and other invertebrates.

Several thousand plants were collected throughout the regions visited by Doctor Mearns, who employed and trained for the work a Wunyamvezi named Makangarri, who soon learned how to make very good specimens and turned out an excellent man in every way.

Anthropological materials were gathered by Doctor Mearns, with some assistance from others. A collection was contributed by Major Ross, an American in the government service at Nairobi.

I have the honor to be, very truly, yours,

THEODORE ROOSEVELT.

Hon. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

STUDIES IN CAMBRIAN GEOLOGY AND PALEONTOLOGY.

During the field season of 1909 I continued my investigations in the geology of the Cambrian and pre-Cambrian rocks of the Bow River Valley, Alberta, Canada, and on the west side of the Continental Divide north of the Canadian Pacific Railway in British Columbia.

The first camp was made on the shores of Lake Louise, southwest of Laggan. From this point work was carried forward on the high mountains east, northeast, and southwest of the lake, and side trips made to the valley of the Ten Peaks and across the Bow Valley in the vicinity of Ptarmigan Lake. Many fine photographs were secured, both of the beautiful scenery and the geological sections, which

are wonderfully well shown above timber line on the higher ridges and peaks.

The measurements of the Cambrian section were carried down to a massive conglomerate which forms the base of the Cambrian system in this portion of the Rocky Mountains. This discovery led to the study of the pre-Cambrian rocks of the Bow River Valley. These were found to form a series of sandstones and shales some 4,000 feet in thickness, that appear to have been deposited in fresh-water lakes prior to the incursion of the marine waters in which the great bed of conglomerate and the Cambrian rocks above were deposited.

Completing the reconnoissance survey of the Bow River area, camp was moved to the Yoho River Canyon. In the Yoho River Canyon, one of the most picturesque and instructive areas in the great Yoho National Park of Canada, a study was made of the north side of the President Range and numerous pictures taken in that vicinity, also from Burgess Pass, north of Field.

A most interesting discovery of unique Cambrian fossils was made near Burgess Pass. Quite a number of specimens were collected before snow drove the party back to Field. Three days were spent on Mount Stephen at the famous trilobite beds before breaking up camp on September 8.

As opportunity offered during the fall and winter, field notes were written up and studies made of the sections obtained during the summer. As the results of these studies two papers are in press in the Smithsonian Miscellaneous Collections, volume 53: No. 6, "Olenellus and other Genera of the Mesonacidæ," and No. 7, "Pre-Cambrian Rocks of the Bow River Valley, Alberta, Canada." Preliminary studies were also made of the unique crustacean fauna found in the middle Cambrian rocks of Burgess Pass.

GEOLOGICAL INVESTIGATIONS IN THE FAR EAST AND IN NEWFOUNDLAND.

In my last report mention was made of a grant to Prof. Joseph P. Iddings for carrying on geological investigations in the Far East. As one of the results of his work the Institution has received an interesting collection of Manchurian Cambrian fossils, as well as collections of fossils from Japan and Java.

The Institution made a small grant to Prof. Charles Schuchert, of Yale University, to enable him to carry on certain geological studies and to obtain a collection of Cambrian fossils from the west coast of Newfoundland, the south shore of Labrador, and the Strait of Belle Isle; also collections to illustrate the transition fauna between the Cambrian and Ordovician.

STUDY OF AMERICAN MAMMALS.

Through the generosity of a friend of the Institution, Mrs. E. H. Harriman, there has been provided a trust fund yielding an income of

$12,000 a year, which is placed under the direction of the Smithsonian Institution for the specific purpose of carrying on scientific studies, particularly of American mammals and other animals, the donor specifying Dr. C. Hart Merriam as the investigator to carry on the work during his lifetime.

BIOLOGICAL SURVEY OF THE PANAMA CANAL ZONE.

The Institution has had in contemplation for some time several important scientific explorations, and it is gratifying to state that it now seems possible that one of them—an exhaustive biological survey of the Panama Canal Zone—will be undertaken in the winter of 1910–11. Definite plans for this survey have not been decided upon at present, but these are now under consideration and it is hoped that all the arrangements may be completed and the work put in hand in a few months.

It is particularly important to science that a biological survey of the Canal Zone be made at this time, as it appears without question that it would yield important scientific results, both as regards additions to knowledge and to the collections of the United States National Museum and other museums. While the Isthmus is not so well endowed with large forms as the great continental areas, such as Africa, southern Asia, and some other regions, yet its fauna and flora are rich and diversified. The collecting which has been carried on there has been on such a rather limited scale, and chiefly along trade routes, that an extensive and thorough survey would surely produce new scientific information of great value.

A part of the fresh-water streams of the Isthmus of Panama empty into the Atlantic Ocean and others into the Pacific Ocean. It is known that a certain number of animals and plants in the streams on the Atlantic side are different from those of the Pacific side, but as no exact biological survey has ever been undertaken the extent and magnitude of these differences have yet to be learned. It is also of the utmost scientific importance to determine exactly the geographical distribution of the various organisms inhabiting those waters, as the Isthmus is one of the routes by which the animals and plants of South America have entered North America and vice versa. When the canal is completed the organisms of the various watersheds will be offered a ready means of mingling together, the natural distinctions now existing will be obliterated, and the data for a true understanding of the fauna and flora placed forever out of reach.

By the construction of the Gatun dam a vast fresh-water lake will be created, which will drive away or drown the majority of the animals and plants now inhabiting the locality, and quite possibly exterminate some species before they become known to science.

The National Museum at present has practically no Panama mammals. The birds now in the collection are chiefly from along the line of the railroad and from Chiriqui. It has comparatively few reptiles. The fresh-water fishes are poorly represented in the collections and are of special importance for comparison with South American forms. Land and fresh-water mollusks are much needed. The National Herbarium is poorly supplied with Panama plants; in fact, they are at present practically "a negligible quantity," and the American herbariums taken together do not contain a sufficient amount of material to form the basis of a general flora of Panama, which is a work much needed.

ANTIQUITY OF MAN IN SOUTH AMERICA.

In March, 1910, the Institution directed Dr. Aleš Hrdlička, Curator of the Division of Physical Anthropology, United States National Museum, to proceed to South America and Panama Canal Zone for the purpose of making anthropological researches, and particularly to undertake investigation into the question of man's antiquity in Argentina. A grant was also made to enable Mr. Bailey Willis, of the United States Geological Survey, proceeding on his way to South America in the interest of the world's topographical map, to cooperate with Doctor Hrdlička in his researches in Argentina, for it was appreciated that the problems to be met with were to an important degree of a geological nature.

The undertaking of the investigation was especially due to Mr. W. H. Holmes, Chief of the Bureau of American Ethnology, whose observations during a visit to Argentina in 1908 made apparent the far-reaching importance of the data being collected bearing on human antiquity in South America.

The subject of man's antiquity in South America dates from the meager reports concerning the scattered remains in the Lagoa Santa caves in Brazil, the casual Seguin finds in the province of Santa Fe, Argentina, and the Moreno collection of old Patagonian material in the valley of Rio Negro, and it has assumed a special importance during the last decade through a relatively large number of reports by Argentinian scientists, but particularly by Prof. F. Ameghino, of new finds of the remains of ancient man and of traces of his activities. Some of these more recent finds were so interpreted that, if corroborated, they would have a most important bearing not merely on man's early presence in the South American Continent, but on the evolution and the spread of mankind in general.

Under these conditions, and in view of the fact that some of the reports were not fully satisfactory as to their anatomical or geological details, it was deemed necssary to send down competent men who might subject the whole matter to critical revision.

It is gratifying to state that on arriving at Argentina and explaining their mission the Smithsonian representatives were afforded by the Argentinian Government, as well as by the Argentinian men of science, all facilities needed for the examination of the specimens preserved in various institutions, as well as for the prosecution of their field work. Professor Ameghino and his brother, Carlos, gave particular aid, accompanying Doctor Hrdlička and Mr. Willis personally for over three weeks along the coast from place to place where the supposedly ancient remains were discovered.

The researches occupied nearly two months. Every specimen relating to ancient man that could still be found was examined, and every locality of importance where the finds were made was visited and investigated. The evidence gathered, unfortunately, does not sustain a large part of the claims that have been made. The human bones and the archeological specimens which should represent geologically ancient man agree in all important characteristics with the bones and work of the American Indian; and the finds, while often in close relation with early Quaternary or Tertiary deposits, bear, so far as observed, only intrusive relations to these deposits. Furthermore, there are specimens the original sources of which are not so well established that scientific deductions of great consequence can be safely drawn therefrom, even though they present some morphological peculiarities.

The expedition secured numerous geological, paleontological, and anthropological specimens, some of which throw much light on the question of the antiquity of the finds to which they relate. These specimens are being identified and described in the National Museum. Doctor Hrdlička and Mr. Willis will present in due time a detailed report on their investigations.

Following the researches in Argentina, Doctor Hrdlička visited several of the anthropologically important localities on the coast of Peru and made large collections of skeletal material, which will help to settle definitely the racial problems of these regions, and will have an important bearing on the anthropology of the western part of South America.

Further explorations and collections, necessarily limited, were made by Doctor Hrdlička in Panama and Mexico. In the latter country the principal results of the visit were the opening, at the invitation of the Mexican authorities, of a highly interesting sepulcher in the ancient ruins of San Juan Teotihuacan, and the making of a series of casts from the remaining pure bloods among the Aztec descendants in Xochimilco.

The Argentina, as well as the Peruvian and Mexican, collections have been transferred to the U. S. National Museum.

RESEARCHES UNDER HODGKINS FUND.

Flying organs of insects and birds.—Under the direction of Professor von Lendenfeld, of Prague University, aided by a grant from the Hodgkins Fund, there has been carried on for the past ten years investigations on the flying organs of various insects and birds. Some of the results of these studies have been published in the Smithsonian Miscellaneous Collections in papers by Dr. E. Mascha on "The structure of wing feathers," Dr. Leo Walter on "The clasping organs attaching the hind to the fore wings in hymenoptera," and Dr. Bruno Müller on "The air sacs of the pigeons."

There was received during the past year and prepared for press a fourth paper on "The flying apparatus of the blow-fly."

These investigations were fostered by the late Secretary Langley with the hope that they would yield information useful to engineers and others interested in the problem of flight. It was the opinion of the investigator that of all the forms of insects, and indeed of all flying animals, the Diptera, such as the blow-fly, furnish the most promising pattern for a flying machine and that a working model should be built according to this pattern and experimented with.

Mount Whitney Observatory.—The construction on Mount Whitney, California, of a small steel and stone house to serve as a shelter for observers and investigators during the prosecution of researches on atmospheric air and other cognate subjects was authorized October 30, 1908, by an allotment from the Hodgkins Fund.

This spot had been selected as an observation point by the late Secretary Langley as far back as 1881, and had been visited later by other scientific investigators, including Professor Campbell, of the Lick Observatory, and Director Abbot, of the Smithsonian Astrophysical Observatory, each of whom realized the unusual advantages offered by this mountain as a site for a meteorological and atmospheric observatory.

Before erecting the shelter it was necessary to build a trail to the top of the peak, 14,502 feet above sea level, in order to transport the building material, supplies, and instruments. Many dangers and hardships were undergone by the men who accomplished this work, but finally the trail was completed and the equipment packed up the mountain.[a]

The actual work of construction of the shelter was begun July 28, 1909, when the first pack train reached the summit, and was quite completed by August 27, 1909, when summer observations were begun by Director Abbot, of the Smithsonian Astrophysical Observ-

[a] A more detailed account of the work, "A shelter for observers on Mount Whitney," by C. G. Abbot, was published January 12, 1910, in the Smithsonian Miscellaneous Collections, vol. 52, pp. 499–506.

atory, and Director Campbell, of the Lick Observatory, who was engaged in a study of the spectrum of Mars.

The erection of the shelter has already proved a most beneficial undertaking, and it will undoubtedly serve for many years as such for observation parties not only of the Smithsonian Institution but of other institutions desiring to benefit by the conditions and advantages offered to scientists by this exceptional location. Applications for permission to use this shelter by scientific research parties should be made to the Secretary.

Relation of atmospheric air to tuberculosis.—In February, 1908, the Institution offered a prize of $1,500 for the best treatise on "The relation of atmospheric air to tuberculosis," to be awarded in connection with the International Congress on Tuberculosis held in Washington in September of that year, but owing to the great work of translating, reading, and classifying the 81 papers submitted, the committee on award has not, as yet, made a final report; although much progress is reported and the final announcement is excepted shortly.

Publications under Hodgkins Fund.—There was published during the year as a Hodgkins Fund publication a volume on "Mechanics of the Earth's Atmosphere," consisting of a series of 25 papers translated from the French and German by Professor Abbe, and forming a connected treatise on that subject.

Another volume issued at the cost of the Hodgkins Fund was an exhaustive bibliography of aeronautical literature compiled by Mr. Paul Brockett, and containing titles of 13,500 papers on aviation in all languages published previous to July 1, 1909.

THE SMITHSONIAN TABLE AT THE NAPLES ZOOLOGICAL STATION.

For over seventeen years the Institution has maintained at the Naples Zoological Station a table for the use of American biologists, and the lease has been renewed for a period of three years from January 1, 1910, at an annual rental of 2,500 francs.

The founder and director of the station, Dr. Anton Dohrn, always showed a most cordial spirit of helpfulness toward the Institution in arranging for its appointees, and it is with particular regret that I report his death, which occurred on September 29, 1909. At the request of the Institution, the Department of State designated the American consul at Naples to represent the Institution officially at the funeral.

Doctor Dohrn has been succeeded by his son, Dr. Reinhard Dohrn, who has expressed his earnest adherence to the policies adopted by his father, and assures the Institution of his hearty cooperation during his administration.

During the year the following American biologists were appointed to the Smithsonian Table:

Prof. H. D. Senior, of the College of Medicine of the Syracuse University, who continued his researches in the angioblast of the trunk in Teleosts through studies of the origin of the circulation in *Amphioxus*.

Dr. R. M. Strong, of the University of Chicago, whose work was confined to some general studies of chromatophores, which occur in two species of Cephalopods and in three species of Crustacea.

Dr. W. D. Hoyt, formerly of Johns Hopkins University, but now of Rutgers College, whose studies comprehended the periodicity in the fruiting and cultural experiments in alternations of generations of marine algæ.

Prof. Charles L. Edwards, of Trinity College, who continued his investigations in the variations in *Synapta inhoerens* and other holothurians.

Prof. Charles W. Greene, of the University of Missouri, who worked on the comparative physiology of fishes.

Applications for future occupancy of the Table have been received during the year from Dr. S. R. Williams, of the Miami University, and from Dr. Sergius Morgulis, of Harvard University.

The advisory committee on the Smithsonian Table has, as always, rendered invaluable aid in the examination of the credentials of applicants, and it is desired to here record the Institution's appreciation of their assistance.

During the year an important change in the personnel of the committee took place. Dr. John S. Billings, who served for many years as its chairman, tendered his resignation, and it is much regretted that a relationship so helpful and agreeable has been thus terminated. The Institution is fortunate, however, in securing the cooperation of Dr. Carl H. Eigenmann, professor of zoology at the Indiana University and director of the biological station maintained in connection with that establishment. The present organization of the committee is as follows:

Dr. Theodore Gill, of the Smithsonian Institution, chairman; Dr. C. Wardell Stiles, of the Bureau of Public Health and Marine-Hospital Service, secretary; Dr. E. B. Wilson, of the Columbia University, New York; Dr. Carl H. Eigenmann, of the Indiana University.

PUBLICATIONS.

The principal medium for carrying out one of the fundamental functions of the Institution, "the diffusion of knowledge," is through its publications. The Smithsonian Contributions to Knowledge, the Smithsonian Miscellaneous Collections, and the Smithsonian annual

reports now comprise a library of about 150 quarto and octavo volumes covering practically every branch of scientific knowledge, and if to these be added the publications issued under its direction by the National Museum, the Bureau of Ethnology, and the Astrophysical Observatory, the scientific literature produced through the Institution aggregates about 350 volumes, made up of several thousand memoirs and papers.

The works issued at the expense of the Institution proper are necessarily in limited editions, but they are so distributed to the principal libraries throughout the world as to be available for general reference by all who need them. The annual reports, the general appendix of which is made up of selected papers reviewing progress in scientific work in all its branches, is a public document, and through the liberality of Congress is published in larger numbers than the other Smithsonian series, although the editions of this more popular work are each exhausted soon after publication.

In the series of Contributions, reserved for original additions to knowledge, no memoir was issued during the year.

Langley memoir on mechanical flight.—Two memoirs by the late Secretary Langley, entitled "Experiments in Aerodynamics" and "The Internal Work of the Wind," were printed in 1891 and 1893, respectively, as parts of volume 27 of the Smithsonian Contributions to Knowledge, and several editions of each have since been published. A third memoir, dealing with later experiments to December 8, 1903, to be entitled "Langley Memoir on Mechanical Flight," was to complete that volume. This work was in preparation at the time of Mr. Langley's death in 1906, and the manuscript of the first part covering his experiments down to November, 1896, had been written by him and partially revised for press. The further editorial revision of that part and the completion of part 2 to bring the work down to the close of the experiments on December 8, 1903, was placed in the hands of Mr. Charles M. Manly, who had for several years been Mr. Langley's chief assistant in his experiments. The completed manuscript is now nearly ready for the press and it will probably be published within a few months.

It is hoped that later it may be practicable to have tabulated and published the extensive technical data of observations of the working of the model aerodromes and various types of engines, propellers, planes, and other apparatus with the use of the pendulum and whirling-arm.

It is of interest here to note that on August 6, 1907, a French aviator made a flight of nearly 500 feet with a machine of the Langley type.[a]

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[a] Recent Progress in Aviation. By Octave Chanute. In Journal Western Society of Engineers, vol. 15, No. 2, April, 1910. See also various French and Italian aeronautical periodicals giving some details of these experiments.

Smithsonian Miscellaneous Collections.—Thirty papers were added to the Miscellaneous Collections, including a number of biological and anthropological articles, and four volumes of considerable size on The Mechanics of the Earth's Atmosphere, Landmarks of Botanical History, Bibliography of Aeronautics, and Recalculation of Atomic Weights, all of which are enumerated in detail in the appendix to this report.

Among the papers published just at the close of the year was one by Dr. F. W. Clarke on "Chemical denudation" and one by Dr. George F. Becker on the "Age of the earth."

The Smithsonian Physical Tables have been revised and extended to bring the work within the range of recent advances in the science of physics, and the new edition has been put to press. The several series of Smithsonian meteorological, geographical, physical, and mathematical tables continue to be in demand by students, and new editions are required at comparatively frequent intervals.

As mentioned on another page, three papers have been added to the series descriptive of my researches in Cambrian Geology and Paleontology.

Harriman Alaska Expedition.—Arrangements are being made by which the publication of the series of volumes on the results of the Harriman scientific expedition to Alaska in 1899 will be transferred to the Smithsonian Institution and the work will hereafter be known as the Harriman Alaska series of the Smithsonian Institution. The remainder of the edition of the 11 volumes privately printed, as well as volumes in preparation, will bear special Smithsonian title pages, and all will be distributed under the auspices of the Institution.

National Museum publications.—The National Museum publications during the year included the annual report on its operations, about 50 papers, chiefly biological, in the proceedings, 8 bulletins, and 7 botanical papers in the series of Contributions from the National Herbarium. The most elaborate of these works is Bulletin No. 70, devoted to the National Gallery of Art, by Assistant Secretary Richard Rathbun. This book reviews the history of the Art Gallery and gives a catalogue of the collections with illustrations of some of the most important paintings.

Bureau of Ethnology.—The Bureau of American Ethnology issued five bulletins during the year, including works on the unwritten literature of Hawaii, by Doctor Emerson, and "Antiquities of the Mesa Verde National Park," by Doctor Fewkes.

Society publications.—The annual reports of the American Historical Association and of the National Society of the Daughters of the American Revolution were received from those organizations and communicated to Congress in accordance with their national charters.

Allotments for printing.—The allotments to the Institution and its branches, under the head of public printing and binding, during the past fiscal year, aggregating $72,700, were, as far as practicable, expended prior to June 30. The allotments for the year ending June 30, 1911, are as follows:

For the Smithsonian Institution for printing and binding annual reports of the Board of Regents, with general appendixes	$10,000
For the annual reports of the National Museum, with general appendixes, and for printing labels and blanks, and for the bulletins and proceedings of the National Museum, the editions of which shall not exceed 4,000 copies, and binding, in half turkey or material not more expensive, scientific books and pamplets presented to or acquired by the National Museum library	34,000
For the annual reports and bulletins of the Bureau of American Ethnology, and for miscellaneous printing and binding for the bureau, including the binding in half turkey, or in material not more expensive, scientific books and pamphlets acquired by the bureau library	21,000
For miscellaneous printing and binding:	
International Exchanges	200
International Catalogue of Scientific Literature	100
National Zoological Park	200
Astrophysical Observatory	200
For the annual report of the American Historical Association	7,000
Total	72,700

ADVISORY COMMITTEE ON PRINTING AND PUBLICATION.

The committee on printing and publication has continued to examine manuscripts proposed for publication by the branches of the Institution and has considered various questions concerning public printing and binding. Twenty-five meetings of the committee were held during the year and 106 manuscripts were passed upon. The personnel of the committee is as follows: Dr. Frederick W. True, head curator of biology, United States National Museum, chairman; Mr. C. G. Abbot, director of the Astrophysical Observatory; Mr. W. I. Adams, of the International Exchanges; Dr. Frank Baker, superintendent of the National Zoological Park; Mr. A. Howard Clark, editor of the Smithsonian Institution; Mr. F. W. Hodge, ethnologist, the Bureau of American Ethnology; Dr. George P. Merrill, head curator of geology, United States National Museum; and Dr. Leonhard Stejneger, curator of reptiles and batrachians, United States National Museum.

THE LIBRARY.

The Smithsonian Library as at present organized includes (1) the Smithsonian deposit in the Library of Congress, (2) the Smithsonian office library, (3) the library of the National Museum, (4) the library of the Bureau of American Ethnology, (5) the library of the Astro-

physical Observatory, and (6) the library of the National Zoological Park. The Bureau of Ethnology Library, together with the business offices of the Bureau, was during the past year transferred to the Smithsonian building, where it is more accessible than heretofore for reference.

The total additions to these several libraries during the year aggregated more than 23,000 volumes, pamphlets, and serial publications.

The library of the National Museum, which is subdivided into 31 sectional libraries for the convenience of the several departments and divisions, now numbers 38,300 volumes, 61,858 unbound papers, and 110 manuscripts, and the Bureau of Ethnology library contains 16,050 volumes, 11,600 pamphlets, several thousand periodicals, and a large collection of manuscripts.

The Smithsonian deposit in the Library of Congress was increased by the addition of 2,653 volumes, 2,879 parts of volumes, 1,396 pamphlets, and 623 charts, the total accession entries now having reached the half-million mark. This library is becoming more and more valuable as the sets of transactions and memoirs of the learned institutions of the world and of scientific periodicals are each year made more complete.

There was published during the year a bibliography of aeronautics, prepared by the assistant librarian. This work contains references to about 13,500 books or papers on that subject, most of which are available for reference in Washington, the collection of aeronautical literature in the Smithsonian office library having been greatly increased in recent years.

THE LANGLEY MEDAL.

In memory of the late Secretary Samuel Pierpont Langley and his contributions to the science of aerodromics, the Board of Regents on December 15, 1908, established the Langley medal, "to be awarded for specially meritorious investigations in connection with the science of aerodromics and its application to aviation."

As stated in my last report, the first award of the medal was voted by the Board of Regents to Wilbur and Orville Wright, "for advancing the science of aerodromics in its application to aviation by their successful investigations and by their successful demonstrations of the practicability of mechanical flight by man."

The brothers Wright were immediately communicated with in France and accepted an invitation to be present at the Board meeting of February 10, 1910, to receive the medals in person. On the date mentioned they were introduced to the Board and the formal presentation was made. Dr. Alexander Graham Bell reviewed the progress made in the science of aviation by the investigations and experiments

of Professor Langley, culminating on May 6, 1896, in the demonstration that a model aerodrome heavier than air could support itself and fly under its own power. Professor Langley thus became "the great pioneer of aerial flight."[a]

Senator Lodge made the formal presentation speech, in which he said:

It is peculiarly the characteristic of Americans to be pioneers; pioneers across the great continent on which we live, pioneers by sea, and now pioneers by air; and to Wilbur and Orville Wright, pioneers of what Doctor Langley called "the great universal highway overhead," who by their achievements have added honor to the American name and nation, we now present the first Langley medal that the institution has conferred.

After receiving the medals from the hands of the Chancellor the recipients expressed their great pleasure in being considered worthy of such distinction. Mr. Wilbur Wright called attention to the valuable scientific researches by Professor Langley in matters relating to the physical properties of the air and to the great importance of extending these researches, particularly to determine the coefficient of air pressure; that is, the pressure of wind at a certain speed on a plane of a certain size.

As an indication of their early confidence in the successful solution of the problem of aerial navigation, the Wright brothers said:

The knowledge that the head of the most prominent scientific institution of America believed in the possibility of human flight was one of the influences that led us to undertake the preliminary investigations that preceded our active work. He recommended to us the books which enabled us to form sane ideas at the outset. It was a helping hand at a critical time, and we shall always be grateful.

LANGLEY MEMORIAL TABLET.

In accordance with a resolution adopted by the Board of Regents on December 15, 1908, designs have been prepared, and are under consideration by a special committee, for "the erection in the Institution building of a tablet to the memory of Secretary Langley, setting forth his services in connection with the subject of aerial navigation." The committee's recommendations are that the tablet be modeled in bronze in low relief along the lines of the work of St. Gaudens, to contain a bas-relief of the bust of Mr. Langley, and that in the background there be represented a model of the Langley aerodrome in full flight, with the date of its first flight. The tablet is also to bear the lettering "Samuel Pierpont Langley, 1834–1906, Secretary of the Smithsonian Institution, 1887–1906," and to bear also the text

[a] The full addresses by Doctor Bell and others on this occasion will be printed in the report of the Board to Congress.

of what is known as Langley's Law as to relation of speed to power in aerial motion, as follows:

> These new experiments (and theory also when viewed in their light) show that if in such aerial motion, there be given a plane of fixed size and weight, inclined at such an angle, and moved forward at such a speed, that it shall be sustained in horizontal flight, then the more rapid the motion is, the less will be the power required to support and advance it.

COMMISSION ON ZOOLOGICAL NOMENCLATURE.

An International Commission on Zoological Nomenclature, consisting of five members, was appointed in 1895 by the Third International Zoological Congress, held at Leyden, Holland, for the purpose of studying the various codes of nomenclature and to report upon the same at a later congress. At the congress at Cambridge, England, in 1898, the commission was made permanent and increased to fifteen members. At the Berne Congress, in 1904, the commissioners were divided into three classes of five, each class to serve for nine years.

Committees on nomenclature, to cooperate with the International Commission, have been organized in the United States by the Entomological Society of America, the Association of Economic Entomologists, the American Ornithologists' Union, and the Society of American Zoologists.

A code of nomenclature was adopted at the Berlin congress in 1901 and was amended at the Boston congress in 1907. Prior to the Boston congress a desire had developed among zoologists that the commission should serve as a court of interpretation of the code, and in accordance therewith the commission presented to the Boston congress five opinions, which were ratified by the congress.

Since the Boston meeting a number of questions on nomenclature have been submitted to the commission for opinion. Owing to the amount of time consumed in communicating with the fifteen commissioners it was impossible to act promptly upon these cases, but in December, 1909, the Smithsonian Institution gave a grant to provide for the clerical work for a period of three years, and since that time it has been possible to render the opinions more promptly.

The commission has no legislative power. Its powers are restricted to studying questions of nomenclature, to reporting upon such questions to the international congress, and to rendering opinions upon cases submitted to it.

The Smithsonian Institution has also undertaken the publication of the opinions of the commission for a limited period and their distribution to important libraries and to zoological specialists throughout the world. The first issue of these opinions was in press at the close of the fiscal year and included opinions 1 to 25, covering several

important questions, making a pamphlet of 61 pages. In connection with the summary of each opinion there is given a statement of the case and the discussion thereon by the members of the commission.

The commission has issued the following rules to be followed in submitting cases for opinion:

(1) The commission does not undertake to act as a bibliographic or nomenclatural bureau, but rather as an adviser in connection with the more difficult and disputed cases of nomenclature.

(2) All cases submitted should be accompanied by (*a*) a concise statement of the point at issue, (*b*) the full arguments on both sides in case a disputed point is involved, and (*c*) complete and exact bibliographic references to every book or article bearing on the point at issue.

The more complete the data when the case is submitted, the more promptly can it be acted upon.

(3) Of necessity, cases submitted with incomplete bibliographic references can not be studied, and must be returned by the commission to the sender.

(4) Cases upon which an opinion is desired may be sent to any member of the commission, but—

(5) In order that the work of the commission may be confined as much as possible to the more difficult and the disputed cases it is urged that zoologists study the code and settle for themselves as many cases as possible.

INTERNATIONAL CONGRESSES AND CELEBRATIONS.

Congress of Americanists.—The Institution was represented at the Seventeenth International Congress of Americanists held at Buenos Aires, May 16 to 21, 1910, by three delegates, Dr. Aleš Hrdlička, of the United States National Museum; Mr. Bailey Willis, of the United States Geological Survey; and Rev. Charles Warren Currier, of the Catholic University of America. Doctor Hrdlička reports that the meeting was very well attended, particularly by delegates from the various republics of South America. There were read nearly fifty papers, many of them of considerable interest, and related chiefly to the natives of South America. Mr. Bailey Willis presented a communication on "Changes in the geological environment during the Quaternary period," and Doctor Hrdlička gave a résumé of the present knowledge on "Artificial deformation of the human skull, with special reference to America."

The Institution also appointed Dr. Aleš Hrdlička its representative at the second meeting of the above congress to be held in the City of Mexico, September 7 to 14, 1910.

Upon the suggestion of the Smithsonian Institution, the Department of State designated Doctor Hrdlička, Mr. Willis, and Doctor Currier as representatives of the United States at the above congress at Buenos Aires.

Geological Congress.—Dr. George F. Becker, of the United States Geological Survey, was designated as the representative of the Smithsonian Institution at the Eleventh International Geological Con-

gress at Stockholm, Sweden, in August, 1910. A paper expressing my view on "The abrupt appearance of the Cambrian fauna" was prepared to be read at this congress.

International American Scientific Congress.—Mr. Bailey Willis, of the United States Geological Survey, was appointed a delegate in behalf of the Smithsonian Institution to the International American Scientific Congress to be held at Buenos Aires, July 10 to 25, 1910, on the occasion of the Argentina centennial.

Congress on Ornithology.—Mr. William Dutcher, president of the National Association of Audubon Societies, was designated as the representative on the part of the Smithsonian Institution and United States National Museum at the Fifth International Congress on Ornithology held at Berlin from May 30 to June 4, 1910, and upon the nomination of the Institution Mr. Dutcher was also accredited by the Department of State as a delegate on the part of the United States to that congress.

Zoological congress.—The following gentlemen were designated as delegates to represent the Smithsonian Institution and United States National Museum at the Eighth International Zoological Congress to be held at Graz, Austria, from August 15 to 20, 1910, and the Department of State designated them as delegates on the part of the United States: Dr. Charles Wardell Stiles, of the Public Health and Marine-Hospital Service, and custodian of Helminthological Collections in the National Museum; Dr. Henry Haviland Field, an American naturalist and director of the Concilium Bibliographicum; Dr. William E. Kellicott, professor of biology in Goucher College, Baltimore; and Mr. Austin H. Clark, Assistant Curator of the Division of Marine Invertebrates, United States National Museum.

Congress of Botany.—Dr. Frederick V. Coville, of the United States National Museum, and Dr. Joseph C. Arthur, of Purdue University, were designated as representatives of the Smithsonian Institution to the Third International Congress of Botany held at Brussels May 14 to 22, 1910.

Aeronautical Exposition.—The Institution was invited to exhibit some models of the Langley flying machines at an aeronautical exposition at Frankfort-on-the-Main July 10 to October 10, 1909, but it was impracticable to do more than send a series of photographs of the model machines in flight on May 6, 1896, and August 8, 1903, and some views of the full-size aerodrome on the launching ways near Widewater, Virginia.

Inauguration of President Lowell.—The President and Fellows of Harvard College invited the Smithsonian Institution to be represented by a delegate at the inauguration on October 6 and 7, 1909, of Abbott Lawrence Lowell, LL. D., as the twenty-fourth president of Harvard University. It was my pleasure to attend the ceremonies

at Cambridge as such delegate and to present in engrossed form the greetings and congratulations of the Institution.

University of Oviedo.—The Institution received from the University of Oviedo, Spain, a copy of an address and a medal commemorative of the third centenary of that university.

Russian Entomological Society.—The Institution found it to be impracticable to send a delegate to the fiftieth anniversary of the founding of the Entomological Society of Russia at St. Petersburg March 11, 1910, but forwarded its formal congratulations and good wishes.

Conference of librarians.—Mr. Paul Brockett, assistant librarian of the Institution, was authorized to accept the invitation of the secretary of the Institut International de Bibliographie to take part in and become a member of the Congrès International de Bibliographie et de Documentation to be held at Brussels, Belgium, August 25 to 27, 1910, and he was also designated to represent the Institution in the Congrès International des Archivistes et des Bibliothécaires at the same place on August 29 to 31, 1910.

MISCELLANEOUS.

George Washington Memorial Building.—At the February meeting of the Board of Regents I spoke of the movement of the George Washington Memorial Association to erect in Washington a memorial building, which would be used as a center for the scientific, literary, patriotic, and educational associations of the country. It is believed that such a building would afford a much-needed relief to the present crowded condition of the Smithsonian building, resulting in part by the accommodations offered to the National Academy of Sciences, the American Association for the Advancement of Science, the American Historical Association, and others.

The proposed building would be erected by popular subscription.

Preservation of American antiquities.—Under the requirements of law (act of June 8, 1906), the Institution has continued its consideration of applications for permits to make archeological excavations or collections on the public domain of the United States, including requests for researches in the Aleutian Islands, Arizona, New Mexico, Utah, and California.

Gifts.—Among the gifts to the Institution during the year special mention may be made of the C. Hart Merriam collection of 5,800 specimens of skins of mammals and about 6,000 skulls, including 100 full skulls of mammals and 235 skulls of seals presented by Mrs. Edward H. Harriman.

Additional gifts by Mr. Freer and others are referred to in connection with the National Gallery of Art.

NATIONAL MUSEUM.

A summary of the operations of the National Museum is given as usual in the appendix to this report and full details are set forth by the Assistant Secretary in a separate volume, and need not therefore be fully treated here.

New building.—At the close of the year the exterior of the new Museum building had been practically completed. Several months' work, however, remained to be done to finish the south pavilion or rotunda. Provision has been made for the improvement of the grounds immediately about the building, including granolithic roads and walks, grading, and readjustment of roadways.

The transfer of collections, laboratories, and workshops to the new building has progressed as rapidly as practicable considering that the floor area to be provided with furniture and other new equipment is about 10 acres.

The collections of the National Gallery of Art, as mentioned below, were transferred to the middle hall of the new building and opened to the public in March, and in connection therewith some of the more interesting ethnological groups and historical exhibits were installed in the surrounding hall and adjacent ranges. It was not practicable to open any other portions of the building to the public, although more than half of the natural history collections, both reserve and exhibition, had been transferred to their new quarters.

Art textiles.—The removal of the paintings from the old building has afforded more ample space for the display of the art textiles and fabrics, consisting of laces, embroideries, tapestries, brocades, and velvets; also fans, enamels, porcelains, jewelry, etc. As mentioned in my last report, these objects were brought together at the suggestion of Mrs. James W. Pinchot, who has given personal attention to their collection and arrangement.

Accessions.—The additions to the Museum during the year aggregated 970,698 specimens, as compared with 250,000 in the year preceding. The most noteworthy collection of the year was several thousand specimens of mammals, birds, reptiles, batrachians, and other animals, besides several thousand plants, received from the Smithsonian African Expedition under the direction of Col. Theodore Roosevelt, more fully referred to on another page. Other important accessions in the several departments of the Museum are enumerated by the Assistant Secretary in the appendix to the present report. About 800,000 entomological specimens, received from the Department of Agriculture, were varieties of beetles and other insects injurious to forest trees, which had been accumulated during investigations by the Bureau of Entomology.

Distribution of specimens.—The Museum has taken a special interest for many years, to as great an extent as appropriations would permit, in the preparation and distribution to educational establishments throughout the country of series of duplicate specimens pertaining chiefly to natural history. During the past year about 6,000 such specimens were distributed.

National Herbarium.—The removal of the archeological collections from the large upper hall of the Smithsonian building has afforded an opportunity for furnishing adequate quarters for the National Herbarium, which for many years has occupied crowded and unsuitable space in the galleries of the National Museum.

Growth of Museum.—The national collections have so increased in size and value as to make them comparable with the similar collections of the greater European countries, and with the occupation of the new building they may now be housed and arranged in an appropriate and convenient manner. This expansion, however, involves a much greater annual expenditure than heretofore, the larger portion of which is called for in connection with the exhibition halls, maintained for the benefit of the public. The extent of these halls has been about trebled, thus offering an opportunity for the preparation and mounting for display of many additional specimens, a work that will be pushed as rapidly as available funds will permit in order that the operations of the Museum may be commensurate with their importance to the public interests and to science.

THE NATIONAL GALLERY OF ART.

As stated in my last report the collections of the National Gallery of Art had then so increased that they could no longer all be accommodated in the old National Museum building, and Congress having failed to authorize the adaptation of the large hall of the Smithsonian building for their proper exhibition, it had become necessary to make preparations for their display temporarily in one of the halls in the new Museum building. The space selected was the central part of the middle hall, 50 feet wide and about 130 feet long, with a central skylight. Screen walls were constructed, divided into seven rooms. An informal opening of the gallery was held on March 17, 1910, which was largely attended.

The collections were increased during the year by the further gift from Mr. William T. Evans of 32 paintings and 1 fire etching on wood, and by a considerable number of loans from various individuals. It became necessary at the close of the year to make preparation for extending the limits of the gallery so as to include the entire space below the skylight in the middle hall.

The history of the gallery and a catalogue of the collections was published during the year in a volume of 140 pages as Bulletin No.

70 of the National Museum. This was prepared by the Assistant Secretary, Dr. Richard Rathbun, who has been most arduous in his efforts to promote the gallery's growth.

On the occasion of the first annual convention of the American Federation of Art, held in Washington May 17–19, 1910, I had the pleasure of presenting a brief account of the National Gallery, and a private view of the collections was extended to the members of the convention and friends on the afternoon of May 17.

The subject is of such importance that it seems proper here to recall in a general way the origin of the gallery and its present condition and needs.

In 1840, while the question of what should be done with the Smithson bequest was under consideration in Congress, a few gentlemen organized the National Institute, which was in 1842 incorporated by Congress for a term of twenty years, at the expiration of which its collections were to be transferred to the Government. This institute collected a few works of art, which were subsequently transferred to the Smithsonian Institution.

The act of 1846 creating the Smithsonian Institution provides that all objects of art belonging to the United States which may be in the city of Washington shall be delivered to such persons as may be authorized by the Board of Regents to receive them and that they shall be arranged and classified in the building erected for the Institution.

In 1849, under the authority of the Regents, Secretary Henry purchased the Marsh collection of engravings and works of art.

In 1858 the collections in the Patent Office Museum were turned over to the Smithsonian Institution, and in 1862 the collections of the National Institute were transferred, on the expiration of its charter. These collections included a few paintings of merit and sundry art objects.

In 1879 the Catlin collection of Indian paintings was presented to the Institution by Mrs. Joseph Harrison, of Philadelphia.

A few additions were made from time to time up to 1906, but they were relatively of little importance, and, with the collections already in hand, were scattered about in the Smithsonian building and the National Museum building erected in 1879.

In 1903, when the will of Harriet Lane Johnston was presented for probate, it was found that she had bequeathed her entire collection of paintings and art objects to the Corcoran Gallery of Art, under certain specific conditions and subject to the provision that in the event of a national art gallery being established in the city of Washington they should be transferred to the said National Art Gallery and become the absolute property of that gallery. The Corcoran Gallery declined the bequest under the conditions, and the

executors of the Johnston estate asked the courts for a construction of the clause in the testament providing that the collection be given to a national art gallery. This suit was filed on February 7, 1905, in the Supreme Court of the District of Columbia, and by an order of the court dated July 18, 1906, the collections were delivered to the Smithsonian Institution on August 3, 1906, the court deciding that there had been established by the United States of America in the city of Washington a national art gallery within the meaning of Harriet Lane Johnston's will.

In 1904, Mr. Charles L. Freer, of Detroit, offered his art collection to the Smithsonian Institution, under certain specified conditions, and also offered to furnish the means for erecting, after his death, a suitable building to receive the collection. This collection was formally accepted by the Regents of the Smithsonian Institution in 1906. It includes more than 2,250 objects, including paintings in oil, water color, and pastel, drawings and sketches, etchings and dry points, lithographs, oriental pottery, and other objects.

The action of Harriet Lane Johnston and Mr. Charles L. Freer called the attention of all interested in art, to the fact that there was a national gallery, and that under the care of the Smithsonian Institution it was making conservative and satisfactory progress.

In March, 1907, Mr. William T. Evans, of Montclair, New Jersey, announced to the Institution his desire to contribute to the National Gallery a number of paintings by contemporary American artists of established reputation. In transmitting the first installment of paintings, he wrote:

> I have every reason to believe that you will like my selections, but should any of the examples not hold well, others can be substituted, as it is my desire to have every artist represented at his best. As already intimated, I intend that the present gift may not be considered as final. Additions may be made from time to time as opportunities occur to secure exceptional works.

Fifty paintings were enumerated in the list which accompanied this letter. Up to June 30, 1910, Mr. Evans had presented 114 selected paintings, representing 80 artists. These, with the paintings already in the possession of the Institution, bring the exhibit now installed in the large hall of the new Museum building to more than 160.

The world-wide interest in the National Gallery has been increasing rapidly during the past three years, and we believe, without question, that the collections will grow quite as rapidly as facilities can be provided for their proper installation and exhibition. The collection, including the Freer collection, is particularly strong in pictures by American artists, and it is well that it should be so, in order that it may have a strong national tone. The Harriet Lane Johnston collection has given the Gallery fine examples of several of the mas-

ters of European art, and we hope that this feature will be strengthened from time to time as the years go on.

The Charles L. Freer collection contains many beautiful paintings by Tryon, Dewing, Thayer, and the unexcelled series of Whistler paintings, pastels, drawings, and sketches; also the beautiful Peacock room. In oriental art the collection representing Japanese and Chinese paintings from the tenth to the nineteenth century can not be duplicated in any single gallery in the world, and the bronzes and pottery are beautiful, and to a large extent unique and of great historical and artistic value.

The question of a suitable building for the great Freer collection has been happily settled by Mr. Freer, but we still have to consider the problem of properly housing and exhibiting the collections now in the new natural history museum building, as their present installation is of a temporary character.

I have hope that some of our strong men or women who have the means will see the great opportunity that is now offered to present to the nation a suitable building that will be an epoch-making incident in the development of national art and a monument to the culture and patriotism of the one so wise as to take advantage of the opportunity.

The American people, as represented by Congress, have just provided a large and beautiful building for the collections of natural history, and in due time it is expected that sufficient interest will be taken in the art collections of the Government to provide a suitable home for them. This, however, is not to be anticipated in the immediate future, although the collections now in hand and what will be inevitably received if accommodations are provided for them will make a most creditable showing.

I have been frequently asked what effect the development of a national art gallery would have upon the Corcoran Gallery of Art at Washington, and in response I have quoted the effect of the establishment of the Leland Stanford University, in California, upon the State University of California. Prior to the establishment of the Leland Stanford University the State University was a relatively small affair. Its friends, realizing that they must approach the standard set by the proposed new university, at once cast about for strong leaders and strong men for their faculty, and the result in a few years was that California had one of the great research universities of the country in the Leland Stanford and one of the great state universities, with thousands of students. The Corcoran Gallery, with its splendid history, fine building, and beautiful collection of paintings and statuary, has an international fame, and will grow stronger and more rapidly under the stimulus of a greater art interest, caused by the development of the national gallery. One will

supplement the other, and anyone visiting Washington at all interested in art will be obliged to visit both.

The most sincere and hearty cooperation has existed in the past between the two institutions, and it will continue in the future, the only rivalry being that each will endeavor to hold to a higher standard and uplift the art ideals in America.

In order to insure the maintenance of the gallery at a proper standard there has been organized a permanent honorary committee of men competent to pass judgment on the quality of such works of art as might be presented for acceptance by the gallery and who are also so identified with the art interests of the country as to assure to the public and especially to the lovers and patrons of art the wholly worthy purpose of this movement on behalf of the nation. This advisory committee is constituted as follows:

Mr. Francis D. Millett, president; Mr. Frederick Crowninshield, representing the Fine Arts Federation, of which he is president; Mr. Edwin H. Blashfield, representing the National Academy of Design; Mr. Herbert Adams, representing the National Sculpture Society, of which he is president; and Mr. William H. Holmes, of the Smithsonian Institution, secretary of the committee.

BUREAU OF AMERICAN ETHNOLOGY.

The Bureau of American Ethnology has in the past accomplished much in its study of the habits, customs, and beliefs of the American aborigines. The results of these researches have in considerable measure been permanently recorded in annual reports and bulletins that contain a mass of valuable information on aboriginal arts and industries, forms of government, religious and social customs, languages, and mental and physical characteristics. Although a large body of material still awaits final study and arrangement and much remains to be done both in field and office work, yet the investigations of the Bureau have reached such a stage as to render it possible to summarize some of the results in the form of handbooks designed especially for the use of schools and nonprofessional students. The demand for the handbooks already issued or in preparation has been very large.

The Indians form one of the great races of mankind, and the world looks to the Government for all possible knowledge that is still available concerning this race before it shall have vanished by assimilation in the great body of the American people.

The Bureau has likewise done much in the exploration and preservation of antiquities, especially the prehistoric ruins in the southern Rocky Mountain region, and will continue work in this direction and press it more rapidly while there is still opportunity to save them

from vandalism and to preserve them for the benefit of future generations.

There is present need of ethnological researches among the tribal remnants of the Mississippi basin, since the opportunities for making and preserving a permanent record of the aborigines which played such an important part in the early history of the Middle West are rapidly passing.

Ethnological researches should also be made in the Hawaiian Islands and in Samoa. Little reliable information regarding the ethnology of these insular possessions has been recorded, and it is hoped that Congress may soon provide the means for initiating among their natives researches of the same general character as those now being conducted among the American Indian tribes.

The various lines of ethnological studies carried on by the Bureau during the past year are presented in detail in the appendix to the present report.

The removal of some divisions of the National Museum to the new Museum building afforded an opportunity for the transfer in December last of the offices and library of the Bureau of American Ethnology from rented quarters to the Smithsonian building. It was found desirable at the same time to reorganize the office force, Mr. Holmes, Chief of the Bureau for several years, having resumed the office of head curator of the Department of Anthropology in the National Museum.

With a view to economy in the transaction of the routine business of the Bureau, much of the clerical and all the laboring work was concentrated by placing the routine correspondence and files, the accounts, the shipment of publications, and the care of supplies and other property in immediate charge of the office of the Smithsonian Institution. It was thus found possible to render a larger proportion of the annual appropriation available for research work.

INTERNATIONAL EXCHANGES.

Several additional governments have entered into the immediate exchange of their parliamentary records during the past year, 26 countries now taking part in this exchange with the United States. A list of the countries to which the daily issue of the Congressional Record is sent will be found in the appended report on the exchanges. The Institution is still in correspondence with other governments regarding this immediate exchange, and from time to time additions will no doubt be made to the list of those countries participating. It may be stated, in this connection, that the exchange here alluded to is separate and distinct from the exchange of official documents which has existed between the United States and other countries for a number of years.

While the number of packages handled during the past year was 7,250 less than during the preceding twelve months, there was a gain in weight of 8,515 pounds. The number of packages passing through the service was 221,625, and the total weight 484,684 pounds.

The total available resources for carrying on the system of exchanges during 1910 amounted to $36,646.74—$32,200 of which were appropriated by the Congress and $4,446.74 were derived from exchange repayments to the Institution.

His Imperial Japanese Majesty's residency-general at Seoul having consented to act as the exchange intermediary between Korea and the United States, the interrupted exchange relations with that country have been resumed.

Under the exchange arrangements entered into in 1898, through the Imperial Academy of Sciences, in Vienna, with the Statistical Central Commission, it has been necessary for the Smithsonian Institution to bear all the expenses for freight on consignments both to and from Vienna. The government of Austria has now signified its willingness to assume its share of the cost of conducting the exchanges between the two countries, and in the future the Institution will, therefore, be relieved of this extra burden upon its resources. In bringing this matter to the attention of the Austrian Government, the Institution has had the assistance of the presidents of the Imperial Academy of Sciences and of the Statistical Central Commission, to both of whom thanks are due for their kind cooperation.

During the past year the Institution discontinued sending exchange packages to correspondents by registered mail. This step was taken with a view to reducing the work in the exchange office and also to relieving the Post-Office Department of the extra expense involved in handling the large amount of registered matter sent out by the exchanges.

There were 975 more correspondents on the records of the exchange office than at the close of last year, the total now being 63,605.

The circular containing the exchange rules has been revised during the year and a new edition printed. For the information of those who may wish to make use of the facilities of the service, the circular is given in full in the report on the exchanges.

German bureau of exchanges.—As has been mentioned in previous reports, the German Government has never undertaken the distribution of exchanges between Germany and the United States, and, in order to conduct the very large interchange of publications between the two countries, it has been necessary for the Smithsonian Institution to maintain a paid agency in Leipzig. During the year 1907, Germany was again approached, through the Department of State, on the subject of the establishment of a governmental bureau of exchanges in that country. It is gratifying to note here that the repre-

sentations of the department through the American ambassador at Berlin, have been given favorable consideration on the part of the German authorities, in connection with the establishment, under the direction of that Government, of the America Institute in Berlin—an institution for the fostering of cultural relations between Germany and the United States. While the Smithsonian Institution has not thus far received definite information of the actual establishment of this institute, it is learned through Dr. Hugo Münsterberg—Harvard exchange professor to the University of Berlin, who is to be the first director of this America institute, and who has taken a very active interest in the whole matter—that it is intended to have the institute assume, as one of is functions, the interchange of publications between Germany and the United States.

NATIONAL ZOOLOGICAL PARK.

The National Zoological Park was established in 1890 "for the advancement of science and the instruction and recreation of the people." The area covered by the park is 167 acres along the Rock Creek Valley, about 2 miles north of the center of Washington, in a region well adapted by nature for the purpose for which it is used. During the past twenty years improvements have gradually been made as appropriations have permitted by the laying out of driveways and walks and the construction of bridges to render access easy for visitors through connections with the city thoroughfares and with the roadways of Rock Creek Park to the north of the Zoological Park. From year to year likewise the comfort and care of the collections have been improved by the laying out of ponds and yards and the construction of bird cages, bear dens, and buildings suited to the habits of the various animals. Among the improvements of the past year I may mention that six new large cages were built for the lions and other large cats; the antelope house was enlarged by an extension 50 by 50 feet, furnishing 10 additional stalls with commodious yards, and a new entrance to the building; and a suitable pool 47 by 96 feet was made for the sea lions and seals.

There remains, however, much to be done to provide adequate accommodations for the collections that are gradually increasing in number and in value, as well as improved facilities for the great and increasing number of visitors to the park.

To a large extent the animals still have to be kept in temporary quarters, which are insufficient and unsuitable, and are costly to maintain because of the repairs that are constantly required. This is especially true of the temporary building used for birds. The park has a fine series of birds, some of them of great rarity and interest, and they would make a most valuable exhibit if properly housed.

Only a part of the collection can now be shown for lack of room, and it is practically impossible to maintain the birds in a healthy condition when kept in such unsuitable quarters.

The collections in the park were enriched during the year by the addition of a number of East African animals, including five lions, two cheetahs, a leopard, a Grant's gazelle, a wart hog, and several smaller mammals and birds, which were the gift of Mr. W. N. McMillan, of Nairobi; also a pair each of eland and Coke's hartebeest, a Grant's zebra, a water buck, and a Lophiomys, which were secured in the same region. These animals were of such interest and value as to render it desirable to send the assistant superintendent of the park to Africa to arrange for their safe transfer to Washington.

ASTROPHYSICAL OBSERVATORY.

The work of the Astrophysical Observatory during the year has brought two important results:

(1) The first result is the establishment of an absolute scale of pyrheliometry within three parts in one thousand as the result of a long series of experiments with various pyrheliometers. The establishment of this scale through Mr. Abbot's standard pyrheliometer has been supplemented by the distribution abroad and at home of several secondary pyrheliometers constructed through a grant from the Hodgkins Fund. The constancy of the scale of these secondary pyrheliometers has been established and it is desirable to compare this scale with those in use elsewhere. It is hoped that finally all pyrheliometric observations will be made on the same scale as that used here.

(2) The second result of the year's work is the agreement within 1 per cent of the "solar-constant" observations obtained by Mr. Abbot at the Smithsonian Mount Whitney station in California at an elevation of 14,500 feet with those obtained simultaneously at the Mount Wilson station in California at an elevation of only 6,000 feet. This determination, in combination with the above-mentioned establishment of an absolute scale of pyrheliometry, gives 1.925 calories per square centimeter per minute as a mean value, for the period 1905–1909, of the rate at which the earth receives heat from the sun when at its mean distance. Determinations made with various forms of apparatus show no systematic difference in this value of the "solar constant." In 1905 this "constant," according to various authorities, was stated at values ranging between 1.75 and 4 calories.

It is improbable that observations would have been continued since 1902 on "solar-constant" work but for a suspected variability of the radiation sent to us from the sun. The laws governing this variability are of extreme importance for utilitarian purposes apart from

their interest to astronomers. While confident of the existence of variations of this value extending over somewhat long periods and of the probability of short-period variations as shown by the observations obtained on Mount Wilson, yet, in order to establish full confidence in the minds of others of this variability of the sun's heat, there is a very pressing need of observations made simultaneously at some other place where they could be made over a longer period than is possible at Mount Whitney. This new station should be so situated that observations could be continued there while the winter rainy season prevents them at Mount Wilson. A station in Mexico would best fulfill such conditions.

INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE.

The purpose of the International Catalogue of Scientific Literature is to collect and publish in 17 annual volumes a classified index of the current scientific publications of the world. This is accomplished through the cooperation of 32 of the principal countries of the world, which by means of regional bureaus, one in each country, prepare the data necessary to index all scientific publications issued within their domains. The material thus prepared is forwarded to a central bureau in London for publication in the annual volumes.

The various subscribers throughout the world bear the entire cost of the actual printing and publication by the central bureau, but each country taking part in the enterprise bears the expense of indexing and classifying its own publications.

The 17 annual volumes combined contain from 10,000 to 12,000 printed pages. The regional bureau for the United States furnishes yearly about 30,000 citations to American scientific literature, which is between 11 and 12 per cent of the total for the world. The bureau for this country was for several years maintained from the funds of the Smithsonian Institution, but is now supported through annual congressional appropriations.

Millions of dollars are being spent each year in scientific investigations, and many of the foremost men of the day are devoting their entire time to such work. The results of their labors find publicity through some scientific journal, of which there are over 5,000 that are regularly indexed by the various regional bureaus, over 500 of these journals being published in the United States. The titles of hundreds of books and pamphlets are likewise cited in this International Catalogue. There is thus furnished in condensed, accurate, and permanent form a minutely classified index to practically all the scientific literature of the world, for the method of classification actually furnishes a digest of the contents, as well as the usual bibliographical data, for each publication.

It is interesting to mention that a plan for a work of this character was proposed by the Smithsonian Institution as early as 1855, when Secretary Henry, of the Smithsonian Institution, called the attention of the British Association for the Advancement of Science to the great need of an international catalogue of scientific works. In 1867 the Royal Society published its well-known "Catalogue of Scientific Papers," and the Smithsonian Institution from time to time has issued catalogues of the literature of special branches of science. In 1894 the Royal Society invited the governments of the world to send delegates to a conference to be held in London in 1896. At this and the following conferences in 1898 and 1900 a plan was formulated to start the work with a classified subject and author catalogue of all original scientific literature, beginning with January 1, 1901.

Respectfully submitted.

CHARLES D. WALCOTT, *Secretary.*

Appendix I.

REPORT ON THE UNITED STATES NATIONAL MUSEUM.

Sir: I have the honor to submit the following report on the operations of the United States National Museum for the fiscal year ending June 30, 1910:

CONSTRUCTION AND OCCUPATION OF THE NEW BUILDING.

The subjects of greatest concern during the past year have been those connected with the erection and occupation of the new building. By the end of the year essentially all of the building except the interior of the south pavilion and the granite approaches had been structurally finished. The last stones in the approaches, however, were laid toward the end of July, 1910, leaving, at the time of writing this report, only the pavilion, or rotunda, which will require several months more for its completion on account of certain decorative features, though these are neither elaborate nor expensive. The auditorium, which occupies most of the ground floor of the pavilion, is expected to be in readiness by October.

In the general deficiency act passed near the close of the last session of Congress provision was made for the improvement of the grounds immediately about the building. This work includes granolithic roads and walks to the north entrance and along both sides of the building to the east and west entrances, where coal, collections, and supplies are delivered; the grading of the embankment just south of the building and the construction of a narrow service road in the intervening area; the sodding or seeding of all surfaces intended to be kept as lawns; and the readjustment of one of the main roads of the Mall so as to cause it to pass directly in front of the south approaches. These important matters will be attended to by the officer in charge of public buildings and grounds, in whose province they belong.

The pressure for additional space on account of the emptying of the rented buildings and the rapid growth of collections made it imperative to begin the occupation of the new building before its completion. During May and June, 1909, the contents of the rented buildings were carried over and stored on some of the finished floors in the exhibition halls and in one of the open courts. Two months later possession of the third story was obtained from the superintendent of construction, although at that time none of the rooms were provided with doors and temporary expedients had to be resorted to for the protection of such material as was first moved. On November 9, 1909, the Museum accepted control of all parts of the building aside from the south pavilion, and while there was still much work of a minor character in progress, operations were not materially interfered with on that account. The transfer of the collections, laboratories, and workshops has proceeded rapidly, but not as satisfactorily as was hoped for, owing mainly to delays in obtaining furniture, an undertaking of great magnitude, considering that the floor area to be provided for is in the neighborhood of 10 acres.

It may be explained that the first and second floors of the building are designed wholly for exhibition purposes. There is one large exhibition hall

on the ground floor, which also contains the heating and power plant, and the wood and metal work shops. Otherwise, this floor, and the third floor and attic, are allotted to the immense reserve collections in all branches of natural history, the laboratories, preparators' rooms and administrative offices. It is planned with reference to these three floors to use only metal furniture as far as possible, especially for the storage of specimens, since the fire risk is greater in the relatively small closed rooms than in the large exhibition halls, through which a clear view can be had at all times. The danger of fire or of its spread has, however, been reduced to a minimum, first through the use of metal doors supplementing the otherwise fireproof construction, and, second, through a system of alarms, fire plugs and fire extinguishers. While the metal as well as wooden storage cases are made in several styles to meet the requirements of different classes of specimens, the rule of construction along unit lines continues to be followed. The large demand created by the needs of the new building has given rise to a keen competition among manufacturers of steel furniture, and resulted in a quality of workmanship which is highly gratifying.

A certain amount of fireproof storage furniture had been constructed during the year 1908–9, but it was not until the beginning of last year that the larger orders could be placed, and a considerable amount of work was also done in the Museum shops. As it was deemed most important to first complete the furnishing of the working quarters, very little has been done in the matter of exhibition cases, but the requirements of the public halls will be given active consideration during the current year.

Considerably more than half of the natural history collections, both reserve and exhibition, were transferred during the year, and it is expected that the entire moving will be completed before winter. The only exhibition series opened to the public were those referred to below in connection with the National Gallery of Art, but the arrangement of other halls was in progress when the year closed. For the division of plants, the second story of the main part of the Smithsonian building is being fitted up.

From what has been said it will be noted that with the readjustments now in progress all of the collections relating to natural history, including anthropology, but excluding the herbarium, will soon be segregated in the new building, which was specially planned for that branch of the Museum. The installation of the paintings of the National Gallery of Art in the middle wing of the building, as described below, is virtually an intrusion, and it is expected that in due time more appropriate accommodations will be found for this important and rapidly growing department.

The great difference in the amount of space required by each of the respective departments and their branches, dependent upon the size of their collections, has rendered impossible any exact division between them of the floor area of the building, and the claims of each has been decided according to the actual needs. In a general way anthropology has been given the middle part of the building, biology the western side, and geology the eastern side. This division of space extends essentially from the ground floor to the attic, and, in view of the many elevators and stairways provided, the arrangement is not inconvenient. It gives to each of the departments one of the large halls, and, as all of these halls open on the rotunda, a visitor entering by the main doorway may proceed directly to whichever department he desires.

NATIONAL GALLERY OF ART.

Mr. William T. Evans contributed 32 paintings and 1 fire etching to his collection of the works of contemporaneous American artists, which now numbers 1[illegible]

well-selected examples by 80 painters. This important gift, which is attracting wide attention and receiving the highest commendation, has already done much toward advancing the interests of American art, and it is worthy of mention that one of its canvases was exhibited abroad in the early spring. It should also be stated that during a trip to the Orient Mr. Charles L. Freer secured many choice additions to his collection, still remaining in his custody in Detroit, the formal transfer of which, as the third supplement to the original gift, was made to the Institution in July, 1910.

Early in July, 1909, it became necessary to move the Evans collection from the Corcoran Gallery of Art to the improvised picture gallery in the older Museum building, and this in turn required the temporary retirement from public view of many of the paintings which had previously been installed there. The importance of having the entire collection kept together and on exhibition, however, led to an arrangement for its maintenance in the new building, pending the time when a more appropriate home can be found for the department of the fine arts. The location selected was the central skylighted part of the middle hall, which is 50 feet wide and has been utilized to a length of about 130 feet. This area was inclosed with screen walls of a suitable character for hanging paintings and was divided into 7 rooms of varying size. Here all of the paintings belonging to the gallery, together with many loans, were assembled in time to have an informal opening on the 17th of March, 1910, which was largely attended. Some of the more interesting ethnological groups and historical exhibits were also installed for the same occasion in the surrounding parts of the hall and adjacent ranges, and the first visitors to the new building were, therefore, given the opportunity to judge of its advantages for exhibition purposes. At the close of the year preparations had been made for extending the limits of the gallery so as to include the entire space below the skylight.

ART TEXTILES.

With the removal of the paintings from the gallery in the older Museum building and of the large screens except the one at the east end, this entire hall became available for the collection of art objects commenced two years ago at the suggestion of Mrs. James W. Pinchot, who has continued to give her personal attention to its growth and arrangement. Consisting fundamentally of laces, it comprises other art textiles and fabrics such as embroideries, tapestries, brocades, and velvets; and also fans, enamels, porcelains, silver work, ivory carvings, jewelry, etc. Besides many loans there were two important donations during the year. One was from Mrs. Pinchot and consisted of 61 pieces of lace, purchased abroad expressly for the collection and with a view to its needs. The other was from Miss Anna R. Fairchild, and comprised 12 pieces of lace and 7 fans, formerly belonging to the late Miss Julia S. Bryant, in whose memory they were presented. The laces are of several varieties, mostly of large size, dating back to the seventeenth century, and are of great beauty and value. Just before the close of the year additional cases were provided and the entire collection was rearranged. It is now one of the most attractive features in the Museum.

COMMEMORATIVE TABLET.

It is especially pleasing to note the acquisition of a large bronze tablet, interesting both historically and artistically, executed by the sculptor, Isidore Konti, for the Hon. Truxton Beale, who has recognized the National Museum as a fitting place for its installation. It symbolizes an act of heroism during the war with Mexico, by which the two participants, whose figures appear in relief on the tablet, namely, Passed Midshipman (afterwards General) Edward F. Beale

and Kit Carson, obtained succor for a band of American soldiers surrounded by the enemy. This tablet, which measures 11 feet high by 7 feet wide, was erected in the north entrance hall of the new building, and unveiled, with simple ceremonies, on May 31, 1910.

ADDITIONS TO THE COLLECTIONS.

The total number of specimens received during the year was approximately 970,698, of which 933,998 were zoological and botanical, 17,979 were geological and paleontological, and 18,721 belonged to the several divisions comprised in the department of anthropology. The unprecedented record for biology resulted from the transfer of a special large collection from one of the government departments, as explained below. While North America was, as usual, most extensively represented in the additions, the accessions from abroad were exceptionally numerous and valuable, and in a notable degree furnished material for important contributions to science.

The most noteworthy accession was that received from the Smithsonian African Expedition under the direction of Col. Theodore Roosevelt, who was accompanied by his son, Mr. Kermit Roosevelt, and, on the part of the Institution, by Dr. Edgar A. Mearns, U. S. Army, Mr. Edmund Heller, and Mr. J. Alden Loring. This expedition, which was entirely financed from private sources, reached Mombasa on April 21, 1909, spent eight months in British East Africa, and thence proceeded through Uganda and down the White Nile to Khartum, where it arrived on March 14, 1910. Field work was energetically prosecuted in all parts of the region visited and ample notes were made. The resultant collection, sent in several installments, reached Washington in excellent condition, and constitutes the largest and most important single gift of natural history objects ever received by the Museum. A preliminary census indicates that it comprises about 4,897 mammals, 4,000 birds, 2,000 reptiles and batrachians, and 500 fishes, besides large numbers of mollusks, insects, crustaceans, and other invertebrates, and several thousand plants. The series of large and small mammals from East Africa is, collectively, probably more valuable than is to be found in any other museum in the world, its importance depending not so much on the number of new forms as on the fact that it affords an adequate basis for a critical study of the mammal fauna of East Africa and the establishment or rejection of the large number of forms which have been described, especially in recent years, from insufficient material. The series of birds, reptiles, and plants are also exceedingly valuable, and the material representing other groups is certain to furnish interesting results when studied.

An exploration of certain parts of Java by and at the expense of Mr. Owen Bryant, of Cohasset, Massachusetts, assisted by Mr. William Palmer, of the Museum staff, resulted in the acquisition of a large and valuable collection, in which mammals and birds figure most prominently, though reptiles, insects, and marine invertebrates are extensively represented. Dr. William L. Abbott presented an important collection of ethnological objects, together with interesting specimens of mammals, birds, and reptiles, obtained by him in Borneo. Nearly 400 specimens, representing 85 species of birds from the Polynesian Islands, were received as a gift from Mr. Charles H. Townsend, of New York, by whom they were collected several years ago.

The transfers made by the United States Bureau of Fisheries, consisting mainly of material which had been studied and described, and containing a large number of types, were of great value. Of fishes there were about 30,000 specimens, of marine invertebrates about 8,000 specimens, and of reptiles and batrachians about 600 specimens. Except for many fishes from the fresh waters of the United States, the collections were derived almost wholly from the explorations of the steamer *Albatross* in different parts of the Pacific Ocean.

An extensive and very valuable series of crustaceans from the expedition of the British ship *Sealark* to the western Indian Ocean in 1905, and smaller series from the explorations of the French ship *Travailleur* and the German ship *Talisman* in the eastern Atlantic Ocean, were presented to the Museum in return for services in working up the respective collections for publication.

The Bureau of Entomology of the Department of Agriculture transferred to the Museum a most extensive and noteworthy collection, which has been in course of building up for a number of years in connection with investigations on insects injurious to forest trees. It comprises not less than 800,000 specimens, mainly beetles of the family Scotytidæ, and remains in charge of Dr. A. D. Hopkins, of the Bureau, who has been designated as its custodian in the Musuem.

The division of plants received over 33,000 specimens, including about 10,000 obtained during an expedition under the associate curator, Dr. J. N. Rose, to the southwestern United States and western Mexico; the material collected by the Smithsonian African Expedition; exchanges from the Philippine Islands, and transfers from the Department of Agriculture.

In geology and mineralogy some interesting specimens from different parts of the world were secured. The accessions in invertebrate paleontology were not only extensive but also of special importance, having been mainly the results of field work conducted during the year under the auspices of the Institution, the Museum, and the Geological Survey, accompanied by stratigraphic observations, and furnishing material for investigations of exceptional value. The largest and most noteworthy collections consisted of Cambrian fossils obtained in Alberta, Canada, by the Secretary, and in Utah and Manchuria, China, by others under his direction. Next should be mentioned Ordovician and Silurian fossils from the Ohio Valley, Utah, and the island of Anticosti, Canada, in part collected by the curator of the division and in part secured by transfer and exchange. Interesting contributions were series of Tertiary fossils from North Carolina and the State of Washington.

A number of remains of rare fossil vertebrates, some in excellent condition for mounting for exhibition, and valuable additions to the collection of mammalian remains from the Fort Union beds of Sweet Grass County, Montana, were obtained in connection with explorations by the Geological Survey and the Museum. The types and figured specimens of Cretaceous plants from New York and New England recently described and published by the Geological Survey constituted the principal acquisition in paleobotany.

Prominent among the accessions in ethnology was a large collection of objects illustrative of the Kanakas of Hawaii, gathered during a long period of years by Dr. N. B. Emerson, of Honolulu, and purchased by the Government for exhibition at the Alaska-Yukon-Pacific Exposition. The most notable of many additions in prehistoric archeology were two collections from North America and one from South America. The former resulted from excavations by Dr. J. W. Fewkes, first at the "Cliff Palace," Mesa Verde National Park, Colorado, for the Department of the Interior, and subsequently at the ruins of the Marsh Pass region, Arizona, for the Bureau of American Ethnology. The latter represents the ancient peoples of Argentina and was obtained by exchange.

Through the courtesy and generosity of the officials of the Metropolitan Museum of Art in New York Dr. Aleš Hrdlička was enabled to visit the excavations which that museum has for some time been conducting in Egypt and to secure from the tombs as they were uncovered several hundred remains of ancient Egyptians, which were carefully labeled and prepared for shipment under his personal supervision. The value of this collection, which is still to be worked up, is greatly enhanced by the fact that every specimen is well identified chronologically.

The technological collections were increased along many lines, the most important additions having been of firearms, including a number of historically interesting pieces, for which the Museum was chiefly indebted to the War Department. Also worthy of mention were series of sun dials and of watch and chronometer movements and the original machine, long in use, by which complete pins were first manufactured automatically.

The division of history was greatly enriched. The bequest of Prof. Simon Newcomb to the nation for deposit in the Museum of many personal memorials comprised, besides his uniform and sword as a rear-admiral in the navy, gold and bronze medals, vases, including a large and fine example in jasper presented by the Emperor of Russia, and 118 diplomas and announcements of honors conferred on this distinguished astronomer by universities and other learned bodies for eminence in science. Among the gifts and loans were personal relics of Admiral Farragut and Rear-Admiral Charles Wilkes, and a number of pieces of china bearing the insignia of the Society of the Cincinnati, made in China in 1790 for David Townsend, of Massachusetts.

MISCELLANEOUS.

Of duplicate specimens from the collections of the various divisions, about 6,000 were distributed to educational establishments in different parts of the country, while about 24,000 were used in making exchanges with other institutions and with individuals, whereby much valuable new material was acquired. The number of specimens sent to specialists for study in behalf of the Museum or of work in progress for other purposes was about 16,000.

The record of visitors to the public halls showed an average attendance, the total number of persons who entered the older Museum building during the year having been about 229,000. It is to be expected that the attendance at the new building when its exhibition collections have been fully arranged will be much greater than this, but not until Sunday opening has been effected, a step anticipated in the near future, can the Museum hope to meet its manifest obligations in popular education.

The publications of the year, all but one of which were descriptive of material in the collections, comprised the annual or administrative report for 1909, one volume of Proceedings, one of Contributions from the National Herbarium, 8 bulletins, and 55 separate papers belonging to three uncompleted volumes.

Because of the insufficient funds provided for the purchase of books the library of the Museum still serves very inadequately the purposes for which it is maintained, the classification of the collections, and important work is often much hindered on this account. At the close of the year it contained 38,300 volumes and 61,858 unbound papers.

Mr. William H. Holmes, who has served as Chief of the Bureau of American Ethnology since 1902, returned to the Museum in January to again take up the duties of head curator of the department of anthropology. It is with deep regret that I announce the deaths, at advanced ages, of two of the honorary associates of the Museum, Dr. Charles A. White and Dr. Robert E. C. Stearns, once active members of its staff, both of whom became widely known through their important contributions to science during many years, the former especially in paleontology, the latter in zoology.

Respectfully submitted.

RICHARD RATHBUN,
Assistant Secretary, in Charge of U. S. National Museum.

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

AUGUST 27, 1910.

Appendix II.

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY.

Sir: I have the honor to submit the following report of the operations of the Bureau of American Ethnology during the fiscal year ended June 30, 1910, conducted in accordance with the act of Congress approved March 4, 1909, authorizing the continuation of ethnological researches among the American Indians and the natives of Hawaii, under the direction of the Smithsonian Institution, and in accordance with the plans of operations approved by the Secretary on June 1, 1909, and January 7, 1910.

During the first half of the fiscal year the administration of the Bureau was under the immediate charge of Mr. William H. Holmes, who, on January 1, 1910, severed his official connection with the Bureau in order to resume his place as head curator of anthropology in the United States National Museum and to become curator of the National Gallery of Art, as well as to enable him to take advantage of the facilities afforded by the change for publishing the results of his various archeological researches. Mr. F. W. Hodge was designated on the same date to assume the administration of the Bureau under the title "ethnologist in charge."

In view of the approaching change and of the necessity for devoting much of his time to affairs connected with the Department of Anthropology of the National Museum and the National Gallery of Art and the administration of the Bureau, Mr. Holmes found it impracticable to give attention to field research during the remainder of 1909. Good progress was made in the preparation of the Handbook of American Archeology, to which he had devoted much attention during the year and to which reference has been made in previous reports.

The systematic ethnological researches of the Bureau were continued as in previous years with the regular force of the Bureau, consisting of eight ethnologists, increased to ten toward the close of the year by the appointment of two additional members of the staff, and finally decreased by the death of one member. In addition, the services of several specialists in their respective fields were enlisted for special work, as follows:

Prof. Franz Boas, honorary philologist, with several assistants, for research in the languages of the American aborigines, particularly with the view of incorporating the results in the Handbook of American Indian Languages.

Miss Alice C. Fletcher and Mr. Francis La Flesche, for continuing the revision of the proofs of their monograph on the Omaha Indians, to be published as the "accompanying paper" of the Twenty-seventh Annual Report.

Miss Frances Densmore, for researches in Indian music.

Mr. J. P. Dunn, for studies of the tribes of the Algonquian family residing or formerly resident in the Middle West.

Rev. Dr. George P. Donehoo, for investigations in the history, geography, and ethnology of the tribes formerly living in western Pennsylvania and southwestern New York, for incorporation in the Handbook of American Indians.

Mr. William R. Gerard, for studies of the etymology of Algonquian place and tribal names and of terms that have found their way into the English language, for incorporation in the same work.

Prof. H. M. Ballou, in conjunction with Dr. Cyrus Thomas, for bibliographic research in connection with the List of Works Relating to Hawaii, in course of preparation for publication.

The systematic ethnological researches by members of the regular staff of the bureau are summarized as follows:

Mr. F. W. Hodge, ethnologist-in-charge, when administrative work permitted devoted his attention almost exculsively to the editing of the Handbook of American Indians (pt. 2), which was so far advanced toward completion at the close of the fiscal year that it seemed very probable the volume would be ready for distribution within about six months. As the work on part 2 was in progress, advantage was taken of the opportunity afforded by the necessary literary research in connection therewith to procure new data for incorporation in a revised edition of the entire work, which it is proposed to issue as soon as the first edition of part 2 has appeared. The demand for the handbook is still very great, many thousands of requests having been received which could not be supplied owing to the limited edition.

With the exception of a brief trip, Mr. James Mooney, ethnologist, remained in the office throughout the entire fiscal year, occupied chiefly in the elaboration of his study of Indian population, with frequent attention to work on the Handbook of American Indians, and to various routine duties, especially those connected with supplying information to correspondents. The investigation of the former and present population covers the entire territory north of Mexico, from the discovery to the present time, and involves the close examination of a great body of literature, particularly documentary records of the various colonies and of the official reports of French and Spanish explorers and commanders, together with such special collections as the Jesuit Relations and the annual Indian reports of the United States and Canadian governments from the beginning. It is also necessary, first, to fix and differentiate the tribe, and then to follow the wasting fortunes of each tribe and tribal remnant under change of name and habitat, further subdivision, or new combination, to the end. For better handling, the whole territory has been mapped into fifteen sections, each of which has its own geographic and historical unity, and can thus be studied separately. The investigation includes a summary of the Indian wars, and notable epidemics within the same region from the discovery. No similar investigation has ever before been attempted, even the official Indian reports being incomplete as to identity of tribes and number of Indians not directly connected with agencies.

In January, 1910, by request of those organizations, Mr. Mooney was designated to represent the Bureau of American Ethnology at the joint meeting of the Mississippi Valley Historical Association and the Nebraska State Historical Society, held at Lincoln, Nebraska, and delivered several addresses, with particular reference to the utilization of the methods and results of the Bureau in local ethnologic and historical research.

At the request of the Secretary of the Interior, Dr. J. Walter Fewkes, ethnologist, continued the excavation and repair of the prehistoric ruins in the Mesa Verde National Park, in southern Colorado, begun in the previous year. Doctor Fewkes commenced work on Cliff Palace in May, 1909, and completed the excavation and repair of this celebrated ruin in August. He then proceeded to northwestern Arizona, and made a reconnoissance of the Navaho National Monument, visiting and studying the extensive cliff and other ruins of that section, knowledge of the existence of which he had gained many years ago during his ethnological researches among the Hopi Indians. At the close of this investigation Doctor Fewkes returned to Washington and prepared for the Secretary of the Interior a report on the excavation and repair of Cliff Palace, which was published by the Department of the Interior in November. A more

comprehensive illustrative report on the same ruins, giving the scientific results of Doctor Fewkes's studies during the progress of the excavation of Cliff Palace, was prepared for publication as Bulletin 51 of the Bureau of American Ethnology and is now in press, forming a companion publication to his description of Spruce-tree House, published earlier in the fiscal year as Bulletin 41. Doctor Fewkes prepared also a report on his preliminary researches in the Navaho National Monument, which is in type and will be published as Bulletin 50. During the remainder of the winter and spring, Doctor Fewkes was occupied in the preparation of a monograph on Casa Grande, an extensive ruin in Arizona, excavated and repaired by him during previous years. He gave some time also to the elaboration of an account of antiquities of the Little Colorado Valley, a subject to which he has devoted considerable study. This work was interrupted in May, 1910, when he again departed for the Navaho National Monument for the purpose of continuing the archelogical studies commenced during the previous field season. At the close of the year Doctor Fewkes was still at work in this region.

Owing to the large amount of material in process of publication as a result of his own researches or assigned to him by reason of his special knowledge of the subjects involved, Dr. John R. Swanton, ethnologist, devoted the year entirely to office work. Much of this time was spent in proof reading (1) Bulletin 43, Indian Tribes of the Lower Mississippi Valley and Adjacent Coast of the Gulf of Mexico, the result of personal field investigations and historical study; as well as in proof reading (2) Bulletin 46, a Choctaw Dictionary, by the late Cyrus Byington; and (3) Bulletin 47, on the Biloxi Language, by the late J. Owen Dorsey, arranged and edited by Doctor Swanton, who incorporated therein the related Ofo material collected by him in 1908 and added a brief historical account of the Ofo tribe. In connection with his researches on the Southern tribes or tribal remnants, Doctor Swanton has revised and rearranged the Attacapa, Chitimacha, and Tunica linguistic material collected by the late Dr. Albert S. Gatschet and has put it almost in final form for the press. With the aid of several texts recorded in 1908, Doctor Swanton has spent some time in studying the Natchez language, preparatory to further investigations among the survivors of this formerly important group, now in Oklahoma. The remainder of his energies has been devoted chiefly to researches pertaining to the Creek Confederacy, with the aid of books and documents in the library of the Bureau and in the Library of Congress, in anticipation of field investigation among the Creek tribes to be undertaken, it is expected, later in 1910.

Mrs. M. C. Stevenson, ethnologist, continued her researches among the Pueblo tribes of the Rio Grande Valley, New Mexico, giving special attention to the Tewa group. As during the previous year her studies were devoted chiefly to the pueblo of San Ildefonso, which offers better facilities for ethnologic investigation than the other Tewa villages, although her inquiries were extended also to Santa Clara and Nambe. Owing to the extreme conservatism of the Tewa people, Mrs. Stevenson found great difficulty in overcoming their prejudices against the study of the esoteric side of their life, but with patience she succeeded finally in gaining the warm friendship of many of the more influential headmen, and by this means was enabled to pursue a systematic study of the Tewa religion, sociology, and philosophy. Like most Indians, the Tewa are so secretive in everything that pertains to their worship that one not familiar with their religious life is readily misled into believing that the ceremonies held in the public plazas of their villages which, with few exceptions, are more Mexican than Indian in outward character, constitute the sole rites of these people, whereas it has been found that the Tewa adhere as strictly

to many of their ancient customs as before white men came among them, although some of their ceremonies are now less elaborate than they were in former times.

While the creation myth of the San Ildefonso Indians differs somewhat from that of the Zuñi and of other Pueblo tribes, it is the same in all essentials. According to their belief they were created in an undermost world, and passed through three other worlds before reaching this one. The tribe is divided into the Sun or Summer, and the Ice or Winter people, the former having preceded the latter in their advent into this world, and their final home was reached on the western bank of the Rio Grande almost opposite the present pueblo. This place is marked by an extensive ruin.

Every mountain peak, near and far, within sight of San Ildefonso is sacred to the Tewa people, and they make pilgrimages at prescribed intervals to lofty heights far beyond the range of their home. The names of these sacred mountains, with a full description of each, were procured.

The philosophy of all the Pueblos is closely related in a general way, yet there are marked differences in detail. Although Mrs. Stevenson has penetrated the depths of the Tewa philosophy, she has not been able to discover any distinctive features, it being a composite of Zuñi, Sia, and Taos beliefs. The great desire of all these people, and the burden of their songs and prayers, is that rain, which in their belief is produced by departed ancestors working behind the cloud-masks in the sky, should come to fructify the earth, and that they may so live as to merit the beneficence of their deities. The entrance to this world is believed to be through a body of water, which the Tewa of San Ildefonso declare existed near their village until certain Zuñis came and spirited the water away to their own country. Further studies, no doubt, will shed more light on these interesting beliefs, and render clearer the origin and relations of Tewa and Zuñi concepts.

There are but two rain priests among the Tewa of San Ildefonso: one pertaining to the Sun people, the other to the Ice people, the former taking precedence in the general management of tribal affairs. The rain priest of the Sun is the keeper of the tribal calendar and is the supreme head of the Sun people. The governor of San Ildefonso, who is chosen virtually by the rain priest of the Sun people, is elected annually, and has greater power than that accorded a Zuñi governor. The war chief, whose religious superior is the war priest, who holds the office during life, is also elected annually, and also is a person of great power. There are three kivas, or ceremonial chambers, at San Ildefonso, one belonging to the Sun people, another to the Ice people, and one used jointly for certain civic gatherings, for rehearsal of dances, and for other purposes. The religion of the Tewa of San Ildefonso consists in worship of a supreme bisexual power and of gods anthropic (embracing celestial and ancestral) and zoic, the latter especially associated with the sacred fraternities. The fundamental rites and ceremonies of these fraternities are essentially alike among all the Pueblos. Their theurgists are the great doctors, whose function is to expel disease inflicted by witchcraft, and those of San Ildefonso have as extensive a pharmacopœia as the Zuñi theurgists. The belief of the Tewa in witchcraft is intense, and is a source of great anxiety among them. Accused wizards or witches are tried by the war chief.

Many of the San Ildefonso ceremonies associated with anthropic worship are identical with those of Taos, while others are the same as those observed by the Zuñi, although neither the ritual nor the paraphernalia is so elaborate. Some of the songs used in connection with the dances at San Ildefonso are in the Zuñi tongue. It is to be hoped that further comparative study among these people will reveal to what extent the ceremonies have been borrowed, like that of the

Koh'-kok-shi of the Zuñi, which is asserted to have been introduced by way of Santo Domingo generations ago by a Laguna Indian who had visited Zuñi.

Mrs. Stevenson devoted much attention to a study of Tewa games, finding that those regarded as of the greatest importance to the Zuñi in bringing rain have been abandoned by the San Ildefonso people. The foot race of the latter is identical with that of Taos, and is performed annually after the planting season. As complete a collection and study of the Tewa medicinal plants were made as time permitted.

The material culture of the Tewa also received special attention. Weaving is not an industry at San Ildefonso, the only weaver in the tribe being a man who learned at Laguna to make women's belts. Basketry of various forms is made of willow. The San Ildefonso people, like other Pueblos, have deteriorated in the ceramic art, and they have now little or no understanding of the symbols employed in pottery, except the common form of cloud and rain. Their method of irrigation is the same as that observed by the neighboring Mexicans, who, having acquired extensive tracts of land from the San Ildefonso land grant, work with the Indians on the irrigating ditches for mutual benefit. The San Ildefonso people raise a few cattle and horses, but no sheep. Much of their land is owned in severalty, and their chief products are corn, wheat, and alfalfa. The women raise melons, squashes, and chile.

While marriages, baptisms, and burials are attended with the rites of the Catholic Church, a native ceremony is always performed before the arrival of the priest. While their popular dances of foreign admixture are sometimes almost depleted by reason of intoxication, no such thing happens when a purely Indian ceremony is performed, for the dread of offending their gods prevents them from placing themselves in such condition as not to be able to fulfill their duty to the higher powers.

Mrs. Stevenson not only prepared the way for a close study of the Tewa of Nambe by making a warm friend of the rain priest of that pueblo, but found much of interest at the Tigua pueblos of Taos and Picuris, especially in the kivas of the latter village. It was in an inner chamber of one of the Picuris kivas that the priests are said to have observed their rites during the presence of the Spaniards. Another interesting feature observed at Picuris was the hanging of scalps to a rafter in an upper chamber of a house, the eastern side of which was open in order to expose the scalps to view. At Picuris the rain priests, like those of Zuñi and San Ildefonso, employ paddle-shaped bone implements (identical with specimens, hitherto undetermined, found in ruins in the Jemez Mountains and now in the National Museum) for lifting the sacred meal during their rain ceremonies.

During a visit to Taos Mrs. Stevenson obtained a full description of an elaborate ceremony performed immediately after an eclipse of the sun.

After her return to Washington, in February, Mrs. Stevenson devoted attention to the preparation of a paper on the textile fabrics and dress of the Pueblo Indians. For comparative studies it was necessary to review a large number of works on the general subject and to examine collections pertaining thereto. Mrs. Stevenson also prosecuted her studies of medicinal and edible plants.

During the entire fiscal year Mr. J. N. B. Hewitt, ethnologist, was engaged in office work devoted chiefly to studies connected with the Handbook of American Indians, especially part 2. A number of articles designed for this work had been prepared by other collaborators, but were recast by Mr. Hewitt in order to embody in them the latest views regarding their subject-matter. Mr. Hewitt also conducted extensive researches into the history of the Indians of the Susquehanna River during the seventeenth century, and their relations with

neighboring peoples, resulting in the discovery that a number of important tribes were designated by the names Susquehanna, Conestoga or Andastes, Massawomek, Erie, Black Minquas, Tehotitachsae, and Atrakwayeronon (Akhrakwayeronon). It is proposed to incorporate this material into a bulletin, with several early maps, in order to make it available to students of the history of the Indians of Pennsylvania and New York, and their relations with white people. Mr. Hewitt also devoted about two months to the translation of Onondaga native texts relating to the New Year ceremony, and began work on the classification of the late Jeremiah Curtin's Seneca legends, with a view of preparing them for publication by the Bureau.

As custodian of the linguistic manuscripts in the Bureau archives, Mr. Hewitt spent considerable time in installing this material, comprising 1,704 items, on its removal from the former quarters of the Bureau to the Smithsonian building. He was frequently occupied also in receiving manuscripts and in searching and charging those required by collaborators either for temporary or for prolonged use. Much time and labor were also devoted by Mr. Hewitt to the collection and preparation of data of an ethnological character for replies to correspondents.

Dr. Cyrus Thomas, ethnologist, while not engaged in revising the proofs of Bulletin 44, Indian Languages of Mexico and Central America and their Geographical Distribution, prepared by him with the assistance of Doctor Swanton, devoted his attention to the elaboration of the List of Works Relating to Hawaii, with the collaboration of Prof. H. M. Ballou. Toward the close of the fiscal year, this work having been practically finished, Doctor Thomas undertook an investigation of the relations of the Hawaiians to other Polynesian peoples, but unfortunately this work was interrupted in May by illness which terminated in his death on June 26. Doctor Thomas had been a member of the Bureau's staff since 1882 and, as his memoirs published by the Bureau attest, one of its most industrious and prolific investigators.

As the result of a special civil-service examination held March 3, 1910, the staff of the Bureau was increased by the appointment, as ethnologists, of Dr. Truman Michelson on June 1 and of Dr. Paul Radin on June 3.

Doctor Radin immediately made preparations to resume his researches among the Winnebago Indians in Nebraska and Wisconsin, commenced under personal auspices three years before, and by the close of the fiscal year was making excellent progress toward completing his studies of this important Siouan group.

About the same time Doctor Michelson departed for Montana with the purpose of studying the Blackfeet, Northern Cheyenne, and Northern Arapaho, Algonquian tribes, whose relations to the other members of the stock are not definitely known. It is the intention that Doctor Michelson obtain a view of the relations of the Algonquian tribes generally, in order that he may become equipped for an exhaustive study of the Delaware and Shawnee tribes, so important in the colonial and later history of the United States. Doctor Michelson reached the Blackfoot country on June 16, and within a few days had recorded a considerable body of ethnological, mythological, and linguistic material relating to the Piegan division.

The special researches of the Bureau in the linguistic field were conducted, as in the past, by Dr. Franz Boas, honorary philologist, whose work during the fiscal year resulted in bringing nearly to completion the first volume of the Handbook of American Indian Languages. The whole matter is in type, 735 pages were in practically final form at the close of the fiscal year, and the sketches of only three languages remained to be revised before paging. Besides the purely technical work of revising and proof reading, the most important work on the

first volume was a thorough revision of the Algonquian sketch by Dr. William Jones, who had planned to make certain additions to the manuscript, but whose unfortunate death in the Philippine Islands left his researches on the Algonquian languages incomplete. The revision was assigned to Dr. Truman Michelson, who made a careful comparison between Doctor Jones's description of the language and his published collection of texts.

Considerable progress was made on the preparation of the second volume of the Handbook of American Indian Languages. Owing to the increase in size of a number of the original sketches, which was due to the lapse of time since they were first recorded, the first volume had increased so much in size that it became necessary to relegate the Takelma to the second volume.

At the beginning of the fiscal year Dr. Leo J. Frachtenberg carried on investigations under the direction of Doctor Boas among the Coos Indians of Oregon. He succeeded in collecting a considerable body of texts from the survivors, and at the same time revised the material collected several years ago by Mr. H. H. St. Clair, 2d. Doctor Frachtenberg completed his studies of the grammar of the language, and the manuscript of this sketch for the second volume was delivered and is partly in type. Toward the end of the year Doctor Frachtenberg made preparatory studies on the Alsea language of Oregon, based on manuscript texts collected a number of years ago by Prof. Livingston Farrand on an expedition due to the generosity of the late Mr. Henry Villard. The completion of the ethnological research work among the Alsea has been provided for by a contribution of funds by Mrs. Villard, which will make it possible to complete also the linguistic investigation of the tribe during the field season of 1910. In June Doctor Frachtenberg visited two survivors of the Willopah tribe who were said to remember the language, but unfortunately only about 300 words could be obtained, and practically no grammatical forms.

Further preparatory work on the second volume of the Handbook of American Indian Languages was carried on by Mr. James Teit, who elucidated the details of the distribution of the Salish dialects of the State of Washington. Part of this work was supported by the generosity of Mr. Homer E. Sargent, of Chicago.

The special researches in Indian music were continued in behalf of the Bureau by Miss Frances Densmore, who has done so much toward preserving the vanishing songs of the Indians. The principal new phase that has arisen in Miss Densmore's work is the importance of the rhythmic unit in Chippewa songs. Her observations indicate that the rhythmic phrase is the essential element of the song; indeed Miss Densmore is inclined to think that the first idea of the song may be a mental rhythm assuming the form of a short unit, and that its expression follows the overtones of a fundamental which exists somewhere in the subconsciousness of the singer. The tabulated analyses show that 99 out of 180 songs to appear in Bulletin 45 (in press) begin on the twelfth or fifth, and 34 begin on the octave—a total of 133 out of 180 beginning on the principal overtones. Of 180 songs, 120 end on the tonic, and yet the tonic does not usually appear until near the close of the song.

Melodic phrases are seldom recurrent. In the oldest songs the words are sung between repetitions of the rhythmic unit, and have a slight rhythm and small melody progressions. Rhythm varies less often than earlier words or melody in repetition, especially when the rhythm is comprised in a definite unit. All these facts emphasize the importance of the rhythm, and also have a bearing on the problem of the development of primitive music, which it is designed to treat in a practical rather than in a theoretical way.

The independence of voice and drum noted by Miss Densmore in previous studies was further shown by the data collected during the year; also the prominence of the descending interval of the minor third, and the marked use of overtones in the choice of melodic material.

The songs collected comprise a group of 40 secured at Ponima, a remote village on the Red Lake Reservation, Minnesota, and the series of war songs which Miss Densmore is now completing and which she expects to finish before the close of the calendar year. It is the intention to combine the analyses of these with the analyses contained in Bulletin 45 of the Bureau, always bringing forward previous work, in order that the results may be cumulative. It is Miss Densmore's desire, before leaving the Chippewa work, to analyze about 500 songs collected from a representative number of localities, as the data derived from systematic analyses of that number of songs should be a safe basis for what might be termed a scientific musical study of primitive song.

Miss Alice C. Fletcher and Mr. Francis La Flesche have continued the proof revision of their monograph of the Omaha Indians to accompany the Twenty-seventh Annual Report, a part of which was in page form at the close of the fiscal year.

Mr. J. P. Dunn pursued his studies of the Algonquian tribes of the Middle West under a small allotment of funds by the Bureau, but comparatively little progress was made, as it was found advisable to hold the investigations somewhat in abeyance until two important manuscript dictionaries—one of the Peoria, the other of the Miami language—known to exist, could be carefully examined, with a view of avoiding repetition of effort. Mr. Dunn was enabled, however, to revise and annotate completely a text in the Miami and Peoria dialects recorded by the late Doctor Gatschet.

PUBLICATIONS.

The editorial work of the Bureau was conducted by Mr. J. G. Gurley, who from time to time, as pressure required, had the benefit of the aid of Mr. Stanley Searles. All the publications of the Bureau have passed under Mr. Gurley's editorial supervision, with the exception of part 2 of Bulletin 30 (Handbook of American Indians), which has been in special charge of Mr. F. W. Hodge, editor of the work, assisted by Mrs. F. S. Nichols. In order to facilitate progress in the publication of the Handbook of American Indian Languages, the editor thereof, Dr. Franz Boas, assumed entire charge of the proof reading in January, thus enabling Mr. Gurley to devote more time to the numerous other publications passing through press.

In all, the manuscripts of seven publications—Bulletins 37, 44, 45, 48, 49, 50, and 51—were prepared for the Government Printing Office, while proof reading was continued on nine publications—the Twenty-seventh Annual Report and Bulletins 30 (part 2), 38, 39, 40 (part 1), 41, 43, 46, and 47, which were in hand in various stages of progress at the beginning of the fiscal year. The number of publications issued was five—Bulletins 38, 39, 41, 48, and 49. The Twenty-seventh Annual Report is in type and a substantial beginning was made toward putting it into page form. The proof of the "accompanying paper" on the Omaha Indians, by Miss Fletcher and Mr. La Flesche, was critically read by the authors and is in condition to be completed in a few months. Bulletins 37 and 43 are practically ready for the bindery, and Bulletins 40 (part 1) and 45 are nearly as far advanced. Bulletin 44 had the benefit of revision by the principal author, Dr. Cyrus Thomas, shortly before his death, and a second galley proof was received. The first galley proof of Bulletins 50 and 51 was placed

in the hands of the author, Doctor Fewkes, for revision. Owing to the condition of the Bureau's allotment for printing and binding, as reported by the Public Printer, and on his suggestion that the work for the fiscal year be curtailed, Bulletins 46 and 47 were not carried beyond the first galley stage. Appended is a list of the publications above mentioned, with their respective titles and authors:

Twenty-seventh Annual Report (1905–6), containing accompanying paper entitled "The Omaha Tribe," by Alice C. Fletcher and Francis La Flesche.

Bulletin 37. Antiquities of Central and Southeastern Missouri, by Gerard Fowke.

Bulletin 38. Unwritten Literature of Hawaii, by Nathaniel B. Emerson, A. M., M. D.

Bulletin 39. Tlingit Myths and Texts, by John R. Swanton.

Bulletin 40. Handbook of American Indian Languages (Part 1), by Franz Boas.

Bulletin 41. Antiquities of the Mesa Verde National Park: Spruce-tree House, by J. Walter Fewkes.

Bulletin 43. Indian Tribes of the Lower Mississippi Valley and Adjacent Coast of the Gulf of Mexico, by John R. Swanton.

Bulletin 44. Indian Languages of Mexico and Central America, and their Geographical Distribution, by Cyrus Thomas, assisted by John R. Swanton.

Bulletin 45. Chippewa Music, by Frances Densmore.

Bulletin 46. Choctaw Dictionary, by Cyrus Byington, edited by John R. Swanton.

Bulletin 47. A Dictionary of the Biloxi Language, accompanied by thirty-one texts and numerous phrases, by James Owen Dorsey; arranged and edited by John R. Swanton.

Bulletin 48. The Choctaw of Bayou Lacomb, St. Tammany Parish, Louisiana, by David I. Bushnell, jr.

Bulletin 49. List of the Publications of the Bureau of American Ethnology.

Bulletin 50. Preliminary Report on a Visit to the Navaho National Monument, Arizona, by Jesse Walter Fewkes.

Bulletin 51. Antiquities of the Mesa Verde National Park: Cliff Palace, by Jesse Walter Fewkes.

The preparation of the illustrations for the publications of the Bureau and of photographs of Indian types continued in charge of Mr. DeLancey Gill, illustrator, assisted by Mr. Henry Walther. This material consists of 97 Indian portraits from life, 121 negatives and 29 drawings for the Bureau publications, 15 copies of negatives, and 676 photographic prints. As in the past, special attention was devoted to the photographing of the members of visiting deputations of Indians, since by this means favorable opportunity is afforded for permanently portraying the features of many of the most prominent Indians belonging to the various tribes.

LIBRARY.

The library of the Bureau continued in immediate charge of Miss Ella Leary, librarian. During the year about 1,500 volumes and about 600 pamphlets were received and catalogued; and about 2,000 serials, chiefly the publications of learned societies, were received and recorded. One thousand five hundred volumes were sent to the bindery, and of these all but 600 had been bound before the close of the fiscal year. In addition to the use of its own library, it was found necessary to draw on the Library of Congress from time to time for the loan of about 800 volumes. The library of the Bureau now contains 16,050

volumes, about 11,600 pamphlets, and several thousand unbound periodicals. Although maintained primarily as a reference library for the Bureau's staff, its value is becoming more and more known to students not connected with the Smithsonian Institution, who make constant use of it. During the year the library was used also by officers of the executive departments and the Library of Congress.

MANUSCRIPTS.

During the first half of the fiscal year the manuscripts were under the custodianship of Mr. J. B. Clayton, and on his indefinite furlough at the close of 1909 they were placed in charge of Mr. J. N. B. Hewitt, as previously noted. Nineteen important manuscripts were acquired during the year, of which seven are devoted to Chippewa music and are accompanied with the original graphophone records, five relate to the history of the Indians, and seven pertain to Indian linguistics. This enumeration does not include the manuscript contributions to the Handbook of American Indians and the Handbook of American Indian Languages, nor the manuscripts submitted for publication by the members of the Bureau's regular staff.

REMOVAL OF OFFICES.

Quarters in the Smithsonian building having been assigned by the Secretary for the use of the Bureau, and funds having been provided by the sundry civil act for the removal of the Bureau's property, the work of transfer was commenced on December 10, 1909, by removing the library from the third floor of the Adams Building, 1333 F street NW., to the eastern gallery of the bird hall on the main floor of the Smithsonian building. The task was made difficult owing to the necessity of removing the old stacks and the books at the same time, but order was fairly established in about a fortnight and the library again put in service. Not only is more space for the growing library afforded by the new quarters, but increased light and facilities for research make the new library far superior to the old. The northern half of the gallery was made more attractive by painting and by carpeting with linoleum. It is yet lacking in necessary space, but this difficulty will be overcome when that part of the southeastern gallery still occupied by the National Museum is vacated.

The offices and photographic laboratory of the Bureau were removed between December 20 and 31, the former to the second, third, and fourth floors of the north tower of the Smithsonian building and one room (that occupied by the ethnologist-in-charge) on the third floor of the northeastern range; the laboratory to one of the galleries of the old National Museum building, while the stock of publications was given space on the fourth floor of the south tower. Although the quarters of the Bureau are now somewhat scattered, the facilities for work are far superior to those with which the Bureau in its rented offices was obliged to contend, and there is less danger of loss by fire. The cost of the removal, including the taking down and rebuilding of the library bookcases, necessary painting of walls and woodwork, linoleum floor covering, and electric wiring and fixtures, aggregated $1,000, the sum appropriated for the purpose.

PROPERTY.

In addition to the books and manuscripts already referred to, the property of the Bureau consists of a moderate amount of inexpensive office furniture, chiefly desks, chairs, filing cases, and tables, as well as photographic negatives, apparatus, and supplies, typewriters, phonographs, stationery, and the undistributed stock of its publications. The removal of the Bureau and the assign-

ment of its members to less crowded quarters made it necessary to supply a few additional articles of furniture, especially for the library. The entire cost of the furniture acquired during the fiscal year was $243.17.

ADMINISTRATION.

Pursuant to the plans of the secretary the clerical and laboring work of the Bureau was concentrated after the removal to the Smithsonian building by placing the routine correspondence and files, the accounts, the shipment of publications, the care of supplies and other property, and all cleaning and repairs, in immediate charge of the office of the Smithsonian Institution. This plan has served to simplify the administration of the affairs of the Bureau, has prevented duplication of effort, and has resulted in a saving of time and funds.

Respectfully submitted.

F. W. Hodge,
Ethnologist-in-Charge.

Dr. Charles D. Walcott,
Secretary of the Smithsonian Institution.

Appendix III.

REPORT ON THE INTERNATIONAL EXCHANGES.

Sir: I have the honor to submit a report on the operations of the International Exchange Service during the fiscal year ended June 30, 1910.

There was given in the last report a list of the countries to which copies of the daily issue of the Congressional Record were forwarded direct by mail in accordance with the resolution of the Congress approved March 4, 1909, setting aside a certain number of copies of the Record for exchange, through the agency of the Smithsonian Institution, with the legislative chambers of such foreign governments as might agree to send to the United States, in return, current copies of their parliamentary record or like publication. The governments of Baden, Cape of Good Hope, New Zealand, Transvaal, and Western Australia have since entered into this exchange. A complete list of the countries to which the Record is now forwarded is given below.

Australia.	Greece.	Roumania.
Austria.	Guatemala.	Russia.
Baden.	Honduras.	Servia.
Belgium.	Hungary.	Spain.
Brazil.	Italy.	Switzerland.
Canada.	New South Wales.	Transvaal.
Cape of Good Hope.	New Zealand.	Uruguay.
Cuba.	Portugal.	Western Australia.
France.	Prussia.	

There are therefore at present 26 countries with which the immediate exchange is conducted. To some of these countries, however, two copies of the Congressional Record are sent—one to the upper and one to the lower house of parliament—the total number transmitted being 31. The number of copies of the daily issue of the Congressional Record provided for this purpose is 100, the same as the number of copies of official documents set apart for international exchange. The Institution is still in correspondence with other governments regarding this immediate exchange, and the list of those countries participating will no doubt be added to from time to time.

The number of packages handled during the past year was 221,625—a decrease from the number for the preceding year of 7,250. The total weight of these packages was 484,684 pounds—a gain of 8,515 pounds. Regarding the falling off in the number of packages handled, attention should be called to the fact that the increase in 1909 was the largest in the history of the service. Had the increase for that year been normal, the total number of packages for 1910 would have shown a gradual increase over the preceding year. The gain in weight may, to a great extent, be taken as an indication that consignments containing more than one publication were more numerous than during the preceding year. This circumstance is especially true in the case of consignments for the Library of Congress, 38 boxes having been received during the past year for that library and counted as single packages.

The appropriation by Congress for the support of the service was $32,200 (the same amount as was granted for the fiscal years 1908 and 1909), and the sum collected on account of repayments was $4,446.74, making the total available resources for carrying on the system of international exchanges $36,646.74.

The exchange office continues to render assistance to the Library of Congress in obtaining foreign government documents needed to complete its sets.

It is gratifying to state that the exchange relations with Korea, which were interrupted during the late Russo-Japanese war, have been renewed, His Imperial Japanese Majesty's residency-general at Seoul having consented to act as the exchange intermediary between the two countries. The number of publications exchanged between Korea and the United States was never very large, and it is hoped that the establishment of an official medium through which consignments may be forwarded will result in a fuller interchange.

While the K. K. Statistische Central-Commission in Vienna has been acting as the exchange intermediary between Austria and the United States since 1898, it has been necessary for the Smithsonian Institution, under the arrangements entered into through the Imperial Academy of Sciences with the commission, to bear all the expenses for freight on consignments both to and from Vienna. The Government of Austria has now signified its willingness to assume its share of the cost of conducting the exchanges between the two countries, and in the future the Institution will therefore be relieved of this extra burden upon its resources. The exchange work on the part of Austria will continue to be carried on by the Statistical Commission. The thanks of the Institution are due to the president of the Imperial Academy of Sciences and to the president of the Statistical Commission for assistance in this matter.

I am very glad to be able to report that it now seems assured that the Institution will shortly be relieved of the expense of conducting the paid agency which it has maintained for many years in Leipsic to attend to the transmission and distribution of exchanges between Germany and the United States.

It is expected that in a few months there will be established in Berlin, under the auspices of the German Government, an institution to further the cultural relations between the two countries. This establishment will be known as the America Institute, and it will assume as one of its functions the transmission and distribution of German exchanges.

While the America Institute has not yet begun active operations, it is expected that it will be organized at an early day, and that it will be prepared to take over the work of the exchange agency by the end of the calendar year.

Dr. Hugo Munsterberg will be the first director of the America Institute.

It has been the practice of the Institution to forward by registered mail packages received from abroad for distribution in the United States. With a view to reducing the work in the Exchange Office and also to relieving the Post-Office Department of the extra expense entailed in handling this registered matter—numbering annually about 21,000 packages, aggregating a total weight of over 120,000 pounds—the custom of registering exchanges was discontinued on October 17, 1909, consignments now being forwarded by ordinary mail. It should be added in this connection, that the Institution is informed by the Post-Office Department that in the ordinary mail there is an average loss of only 1 package in 15,000.

Exchange consignments form part of the cargo of almost every fast steamship which leaves New York for a foreign port. It is therefore not surprising that occasionally a case is lost through the wrecking of a steamer. During the year a case containing exchanges for miscellaneous addresses in the Transvaal was destroyed while en route to Pretoria, the steamship *Norse Prince*, by which

it was transmitted, having been burned while off the coast of South Africa. The loss at sea during the latter part of 1908 of a case of exchanges for distribution in Egypt should also be noted here. This consignment was forwarded in care of the Egyptian Survey Department under date of October 22, 1908, but definite information concerning its loss has only recently been received. The senders of the packages contained in the consignments referred to were communicated with, and it is gratifying to state that, except in one or two instances, it was possible for them to supply copies of the lost publications. It may be of interest to add here that, so far as reported to the Institution, these are the only instances during the past five years in which the entire contents of exchange consignments have been lost.

INTERCHANGE OF PUBLICATIONS BETWEEN THE UNITED STATES AND OTHER COUNTRIES.

The statement which follows shows in detail the number of packages received for transmission through the International Exchange Service during the year ending June 30, 1910:

Country.	Packages.		Country.	Packages.	
	For.	From.		For.	From.
Abyssinia	1	.....	Denmark	2,082	377
Algeria	156	25	Dominica	37	.....
Angola	16	.....	Dutch Guiana	35	.....
Antigua	40	.....	Ecuador	248	.....
Arabia	27	.....	Egypt	464	3,806
Argentina	3,500	311	Eritrea	1	.....
Austria-Hungary	8,522	5,265	Falkland Islands	2	.....
Azores	41	.....	Fiji Islands	34	.....
Bahamas	36	.....	France	12,850	4,802
Barbados	110	.....	French Cochin China	65	.....
Beira	11	.....	French Guiana	13	.....
Belgium	4,377	3,572	German East Africa	32	.....
Bermudas	48	.....	Germany	24,057	8,032
Bismarck Archipelago	1	.....	Gibraltar	15	.....
Bolivia	178	52	Gold Coast	4	.....
Borneo	6	.....	Grenada	6	.....
Brazil	2,692	385	Great Britain and Ireland	22,197	6,896
British America	7,847	848	Greece	1,649	4
British Burma	20	549	Greenland	9	.....
British Central Africa	1	.....	Guadeloupe	7	.....
British East Africa	22	.....	Gautemala	494	.....
British Guiana	69	.....	Haiti	1,124	.....
British Honduras	68	.....	Hawaiian Islands	25	.....
British New Guinea	5	.....	Honduras	389	.....
Bulgaria	206	9	Hongkong	167	.....
Canary Islands	18	.....	Iceland	52	325
Cape Colony	1,830	29	India	2,793	633
Ceylon	240	.....	Italy	7,282	2,253
Chile	2,251	352	Jamaica	253	2
China	1,720	47	Japan	3,462	63
Colombia	1,298	.....	Java	274	85
Costa Rica	1,463	3	Kongo Free State	3	.....
Cuba	1,825	108	Korea	71	15
Curaçao	22	.....	Lagos	6	.....
Cyprus	6	.....	Liberia	162	1

Country.	Packages.		Country.	Packages.	
	For.	From.		For.	From.
Lourenço Marquez	102	.....	St. Lucia	13	.....
Luxemburg	97	.....	St. Martin	11	.....
Madagascar	34	.....	St. Pierre and Miquelon	16	.....
Madeira	1	.....	St. Thomas	14	.....
Malta	99	.....	St. Vincent	6	.....
Martinique	13	.....	Salvador	169	5
Mauritius	78	.....	Samoa	18	.....
Mexico	1,783	255	Sànto Domingo	19	.....
Montenegro	79	123	Sarawak	4	.....
Montserrat	3	.....	Senegal	5	.....
Morocco	20	.....	Servia	1,429	12
Natal	203	51	Siam	217	.....
Netherlands	3,276	1,488	Sierra Leone	21	.....
Nevis	13	.....	Society Islands	12	.....
Newfoundland	152	1	South Australia	2,021	39
New South Wales	2,896	734	Spain	2,853	269
New Zealand	2,507	110	Straits Settlements	230	.....
Nicaragua	221	.....	Sudan	43	1
Norfolk Island	15	.....	Sweden	3,255	106
Northern Nigeria	5	.....	Switzerland	4,029	1,304
Norway	2,190	514	Tahiti	13	.....
Orange River Colony	115	.....	Tasmania	1,285	2
Panama	128	.....	Transvaal	1,594	24
Paraguay	156	.....	Trinidad	126	.....
Persia	45	.....	Tripoli	2	.....
Peru	1,547	92	Tunis	44	6
Philippine Islands	203	.....	Turkey	1,580	1
Porto Rico	24	.....	Turks Islands	21	.....
Portugal	1,889	992	Uganda	1	.....
Queensland	1,494	76	United States	48,989	173,951
Reunion	30	.....	Uruguay	1,971	62
Rhodesia	66	.....	Venezuela	1,283	10
Roumania	747	33	Victoria	3,618	248
Russia	5,836	2,019	Western Australia	1,564	248
St. Croix	5	.....	Zanzibar	13	.....
St. Helena	4	.....			
St. Kitts	23	.....	Total	221,625	221,625

During the year there were sent abroad 2,033 boxes (an increase over 1909 of 70 boxes), of which 220 contained complete sets of United States Government documents for authorized depositories and 1,813 were filled with departmental and other publications for depositories of partial sets and for distribution to miscellaneous correspondents.

EXCHANGE OF GOVERNMENT DOCUMENTS.

The number of packages sent abroad through the International Exchange Service by United States Government establishments during the year was 138,152, an increase over the number forwarded during the preceding twelve months of 15,812; while 18,017 packages were received in exchange, a decrease of 2,199. This disparity between the number of packages received and those sent may be accounted for largely by the fact that many returns for the publications sent abroad are not made through the Exchange Service, but are for-

warded to their destinations direct by mail. This difference is further due to the practice of sending consignments to the Library of Congress intact, in many cases a whole box of publications being entered on the records of this office as one package.

FOREIGN DEPOSITORIES OF UNITED STATES GOVERNMENT DOCUMENTS.

In accordance with treaty stipulations and under the authority of the congressional resolutions of March 2, 1867, and March 2, 1901, setting apart a certain number of documents for exchange with foreign countries, there are now sent regularly to depositories abroad 55 full sets of United States official publications and 33 partial sets.

While the Statutes at Large have for some years formed part of the sets of government documents provided for international exchange purposes, the Session Laws have only been added during the past year. This addition was made through the efforts of the Library of Congress, a request for the laws having been received from one of the depositories.

The recipients of full and partial sets are as follows:

DEPOSITORIES OF FULL SETS.

Argentina: Ministerio de Relaciones Exteriores, Buenos Aires.
Argentina: Biblioteca de la Universidad Nacional de La Plata.
Australia: Library of the Commonwealth Parliament, Melbourne.
Austria: K. K. Statistische Central-Commission, Vienna.
Baden: Universitäts-Bibliothek, Freiburg.
Bavaria: Königliche Hof- und Staats-Bibliothek, Munich.
Belgium: Bibliothèque Royale, Brussels.
Brazil: Bibliotheca Nacional, Rio de Janeiro.
Canada: Parliamentary Library, Ottawa.
Cape Colony: Government Stationery Department, Cape Town.
Chile: Biblioteca del Congreso Nacional, Santiago.
China: American-Chinese Publication Exchange Department, Shanghai Bureau of Foreign Affairs, Shanghai.
Colombia: Biblioteca Nacional, Bogota.
Costa Rica: Oficina de Depósito y Canje de Publicaciones, San José.
Cuba: Department of State, Habana.
Denmark: Kongelige Bibliotheket, Copenhagen.
England: British Museum, London.
England: London School of Economics and Political Science, London.
France: Bibliothèque Nationale, Paris.
France: Préfecture de la Seine, Paris.
Germany: Deutsche Reichstags-Bibliothek, Berlin.
Greece: Bibliothèque Nationale, Athens.
Haiti: Secrétairerie d'État des Relations Extérieures, Port au Prince.
Hungary: Hungarian House of Delegates, Budapest.
India: Home Department, Government of India, Calcutta.
Ireland: National Library of Ireland, Dublin.
Italy: Biblioteca Nazionale Vittorio Emanuele, Rome.
Japan: Department of Foreign Affairs, Tokyo.
Manitoba: Provincial Library, Winnipeg.
Mexico: Instituto Bibliográfico, Biblioteca Nacional, Mexico.
Netherlands: Library of the States General, The Hague.
New South Wales: Board for International Exchanges, Sydney.

New Zealand: General Assembly Library, Wellington.
Norway: Storthingets Bibliothek, Christiania.
Ontario: Legislative Library, Toronto.
Peru: Biblioteca Nacional, Lima.
Portugal: Bibliotheca Nacional, Lisbon.
Prussia: Königliche Bibliothek, Berlin.
Quebec: Legislative Library, Quebec.
Queensland: Parliamentary Library, Brisbane.
Russia: Imperial Public Library, St. Petersburg.
Saxony: Königliche Oeffentliche Bibliothek, Dresden.
Servia: Ministère des Affaires Etrangères, Belgrade.
South Australia: Parliamentary Library, Adelaide.
Spain: Servicio del Cambio Internacional de Publicaciones, Cuerpo Facultativo de Archiveros, Bibliotecarios y Arqueólogos, Madrid.
Sweden: Kungliga Biblioteket, Stockholm.
Switzerland: Bibliothèque Fédérale, Berne.
Tasmania: Parliamentary Library, Hobart.
Transvaal: Government Library, Pretoria.
Turkey: Department of Public Instruction, Constantinople.
Uruguay: Oficina de Depósito, Reparto y Canje Internacional de Publicaciones, Montevideo.
Venezuela: Biblioteca Nacional, Carácas.
Victoria: Public Library, Melbourne.
Western Australia: Public Library of Western Australia, Perth.
Württemberg: Königliche Landesbibliothek, Stuttgart.

DEPOSITORIES OF PARTIAL SETS.

Alberta: Legislative Library, Edmonton.
Alsace-Lorraine: K. Ministerium für Elsass-Lothringen, Strassburg.
Bolivia: Ministerio de Colonización y Agricultura, La Paz.
British Columbia: Legislative Library, Victoria.
Bremen: Senatskommission für Reichs- und Auswärtige Angelegenheiten.
Bulgaria: Minister of Foreign Affairs, Sofia.
Ceylon: United States Consul, Colombo.
Ecuador: Biblioteca Nacional, Quito.
Egypt: Bibliothèque Khédiviale, Cairo.
Guatemala: Secretary of the Government, Guatemala.
Hamburg: Senatskommission für die Reichs- und Auswärtigen Angelegenheiten.
Hesse: Grossherzogliche Hof-Bibliothek, Darmstadt.
Honduras: Secretary of the Government, Tegucigalpa.
Jamaica: Colonial Secretary, Kingston.
Liberia: Department of State, Monrovia.
Lourenço Marquez: Government Library, Lourenço Marquez.
Malta: Lieutenant-Governor, Valetta.
Montenegro: Ministère Princier des Affaires Étrangères, Cetinje.
Natal: Colonial Governor, Pietermaritzburg.
Newfoundland: Colonial Secretary, St. Johns.
New Brunswick: Legislative Library, St. John.
Nicaragua: Superintendente de Archivos Nacionales, Managua.
Northwest Territories: Government Library, Regina.
Nova Scotia: Provincial Secretary of Nova Scotia, Halifax.
Orange River Colony: Government Library, Bloemfontein.
Panama: Secretaria de Relaciones Exteriores, Panama.
Prince Edward Island: Legislative Library, Charlottetown.

Paraguay: Oficina General de Informaciones y Canjes y Commisaria General de Inmigracion, Asuncion.
Roumania: Academia Romana, Bucarest.
Salvador: Ministerio de Relaciones Exteriores, San Salvador.
Straits Settlements: Colonial Secretary, Singapore.
Siam: Department of Foreign Affairs, Bangkok.
Vienna: Bürgermeister der Haupt- und Residenz-Stadt.

CORRESPONDENTS.

The names of new correspondents in every part of the world are constantly being added to the exchange list, so that they now reach a total of 63,605, an increase of 975 over those of the preceding year. These correspondents are subdivided as follows:

Foreign institutions	3,925
Foreign individuals	8,300
Domestic institutions	16,700
Domestic individuals	34,780

A table showing the number of correspondents in each country at the close of 1907 will be found in the report for that year.

RULES GOVERNING THE TRANSMISSION OF EXCHANGES.

The circular containing the rules governing the transmission of exchanges has been revised during the year, and under date of June 30, 1910, a new edition was published. The circular is here reproduced for the information of those who may wish to make use of the facilities of the service in the forwarding of exchanges:

In effecting the distribution of its first publications abroad the Smithsonian Institution established relations with certain foreign scientific societies and libraries by means of which it was enabled to materially assist institutions and individuals of this country in the transmission of their publications abroad and also foreign societies and individuals in distributing their publications in the United States.

In recent years the Smithsonian Institution has been charged with the duty of conducting the official exchange bureau of the United States Government, through which the publications authorized by Congress are exchanged for those of other governments; and by a formal treaty it acts as intermediary between the learned bodies and literary and scientific societies of the contracting states for the reception and transmission of their publications.

Attention is called to the fact that this is an international and not a domestic exchange service, and that it is used to facilitate exchanges between the United States and other countries only. As exchanges from domestic sources for addresses in Hawaii, the Philippine Islands, Porto Rico, and other territory subject to the jurisdiction of the United States do not come within the designation "international," they are not accepted for transmission.

Packages prepared in accordance with the rules enumerated below will be received by the Smithsonian Institution from persons or institutions of learning in the United States and forwarded to their destinations through its own agents or through the various exchange bureaus in other countries. The Smithsonian agents and these bureaus will likewise receive from correspondents in their countries such publications for addresses in the United States and territory subject to its jurisdiction as may be delivered to them under rules similar to those prescribed herein, and will forward them to Washington, after which the Institution will undertake their distribution.

On the receipt of a consignment from a domestic source it is assigned a "record number," this number being placed on each package contained in the consignment. A record is then made of the entire list of packages under the sender's name, and the separate packages are entered under the name of the person or office addressed. An account is thus established with every correspondent of the Institution, which shows readily what packages each one has sent or received through the Exchange Service. The books are then packed in boxes with contributions from other senders for the same country, and are forwarded by fast freight to the bureau or agency abroad which has undertaken to distribute exchanges in that country. To Great Britain and Germany, where paid agencies of the Institution are maintained, shipments are made weekly; to all other countries transmissions are made at intervals not exceeding one month.

Consignments from abroad for correspondents in the United States and its possessions are distributed by mail under frank, a record having first been made of the name of the sender and of the address of each package.

The Institution assumes no responsibility in the transmission of packages, but at all times uses its best endeavors to forward promptly to destination exchanges intrusted to its care.

The rules governing the Smithsonian International Exchange Service are as follows:

1. Consignments from correspondents in the United States containing packages for transmission abroad should be addressed "Smithsonian Institution, International Exchanges, Washington, D. C."

2. In forwarding a consignment the sender should address a letter to the Institution, stating by what route it is being shipped, and the number of boxes or parcels of which it is composed.

3. Packages should be legibly addressed, using, when practicable, the language of the country to which they are to be forwarded. In order to avoid any possible dispute as to ownership, names of individuals should be omitted from packages intended for societies and other establishments.

4. Packages should be securely wrapped in stout paper and, when necessary, tied with strong twine.

5. No package to a single address should exceed about one-half of one cubic foot.

6. Letters are not permitted in exchange packages.

7. If donors desire acknowledgments, packages may contain receipt forms to be signed and returned by the establishment or individual addressed; and, should publications be desired in exchange, a request to that effect may be printed on the receipt form or on the package.

8. Exchanges must be delivered to the Smithsonian Institution or its agents with all charges paid.

9. The Institution and its agents will not knowingly receive for any address purchased books; apparatus or instruments of any description, whether purchased or presented; nor specimens of any nature except when permission from the Institution has been obtained, and then only under the following conditions:

(*a*) Specimens in fluid will not be accepted for transmission.

(*b*) Botanical specimens will be transmitted at the rate of 8 cents per pound.

(*c*) All other specimens will be transmitted at the rate of 5 cents per pound.

LIST OF BUREAUS OR AGENCIES THROUGH WHICH EXCHANGES ARE TRANSMITTED.

Following is a list of bureaus or agencies through which the distribution of exchanges is effected. Those in the larger and many in the smaller countries

forward to the Smithsonian Institution in return contributions for distribution in the United States:

Algeria, via France.
Angola, via Portugal.
Argentina: Comisión Protectora de Bibliotecas Populares, Calle Peru No. 655, Buenos Aires.
Austria: K. K. Statistische Central-Commission, Vienna.
Azores, via Portugal.
Barbados: Imperial Department of Agriculture, Bridgetown.
Belgium: Service Belge des Échanges Internationaux, Rue du Musée 5, Brussels.
Bermuda. (Sent by mail.)
Bolivia: Oficina Nacional de Estadística, La Paz.
Brazil: Serviço de Permutações Internacionaes, Bibliotheca Nacional, Rio de Janeiro.
British Colonies: Crown Agents for the Colonies, London.[a]
British Guiana: Royal Agricultural and Commercial Society, Georgetown.
British Honduras: Colonial Secretary, Belize.
Bulgaria: Institutions Scientifiques de S. M. le Roi de Bulgarie, Sofia.
Canada. (Sent by mail.)
Canary Islands, via Spain.
Cape Colony: Government Stationery Department, Cape Town.
Chile: Servicio de Canjes Internacionales, Biblioteca Nacional, Santiago.
China: Zi-ka-wei Observatory, Shanghai.
Colombia: Oficina de Canjes Internacionales y Reparto, Biblioteca Nacional, Bogota.
Costa Rica: Oficina de Depósito y Canje de Publicaciones, San José.
Cuba. (Sent by mail.)
Denmark: Kongelige Danske Videnskabernes Selskab, Copenhagen.
Dutch Guiana: Surinaamsche Koloniale Bibliotheek, Paramaribo.
Ecuador: Ministerio de Relaciones Exteriores, Quito.
Egypt: Director-General, Survey Department, Giza (Mudiria).
France: Service Français des Échanges Internationaux, 110 Rue de Grenelle, Paris.
Friendly Islands. (Sent by mail.)
Germany: Karl W. Hiersemann, Königsstrasse 29, Leipzig.
Great Britain and Ireland: Messrs. William Wesley & Son, 28 Essex street, Strand, London.
Greece: Bibliothèque Nationale, Athens.
Greenland, via Denmark.
Guadeloupe, via France.
Guatemala: Instituto Nacional de Varones, Guatemala.
Guinea, via Portugal.
Haiti: Secrétaire d'Etat des Relations Extérieures, Port au Prince.
Honduras: Biblioteca Nacional, Tegucigalpa.
Hungary: Dr. Julius Pikler, Municipal Office of Statistics, City Hall, Budapest.
Iceland, via Denmark.
India: India Store Department, India Office, London.

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[a] This method is employed for communicating with several of the British colonies with which no medium is available for forwarding exchanges direct.

Italy: Ufficio degli Scambi Internazionali, Biblioteca Nazionale Vittorio Emanuele, Rome.
Jamaica: Institute of Jamaica, Kingston.
Japan: Department of Foreign Affairs, Tokyo.
Java, via Netherlands.
Korea: His Imperial Japanese Majesty's Residency-General, Seoul.
Liberia: Department of State, Monrovia.
Lourenço Marquez: Government Library, Lourenço Marquez.
Luxemburg, via Germany.
Madagascar, via France.
Madeira, via Portugal.
Mexico. (Sent by mail.)
Montenegro: Ministère Princier des Affaires Étrangères, Cetinje.
Mozambique, via Portugal.
Natal: Agent-General for Natal, London.
Netherlands: Bureau Scientifique Central Néerlandais. Bibliothèque de l'Université, Leyden.
Newfoundland. (Sent by mail.)
New Guinea, via Netherlands.
New Hebrides. (Sent by mail.)
New South Wales: Board for International Exchanges, Public Library, Sydney.
New Zealand: Dominion Museum, Wellington.
Nicaragua: Ministerio de Relaciones Exteriores, Managua.
Norway: Kongelige Norske Frederiks Universitet Bibliotheket, Christiania.
Panama: Secretaria de Relaciones Exteriores, Panama.
Paraguay: Ministerio de Relaciones Exteriores, Asuncion.
Persia: Board of Foreign Missions of the Presbyterian Church, New York City.
Peru: Oficina de Reparto. Depósito y Canje Internacional de Publicaciones, Ministerio de Fomento, Lima.
Portugal: Serviço de Permutações Internacionaes, Bibliotheca Nacional, Lisbon.
Queensland: Board of Exchanges of International Publications, Parliament House, Brisbane.
Roumania, via Germany.
Russia: Commission Russe des Echanges Internationaux, Bibliothèque Impériale Publique, St. Petersburg.
Saint Christopher. (Sent by mail.)
Salvador: Ministerio de Relaciones Exteriores, San Salvador.
Santo Domingo. (Sent by mail.)
Servia: Section Administrative du Ministère des Affaires Etrangères, Belgrade.
Siam: Department of Foreign Affairs, Bangkok.
South Australia: Public Library of South Australia, Adelaide.
Spain: Servicio del Cambio Internacional de Publicaciones, Cuerpo Facultativo de Archiveros, Bibliotecarios y Arqueólogos, Madrid.
Sumatra, via Netherlands.
Sweden: Kongliga Svenska Vetenskaps Akademien, Stockholm.
Switzerland: Service des Echanges Internationaux, Bibliothèque Fédérale Centrale, Bern.
Syria: Board of Foreign Missions of the Presbyterian Church, New York.
Tasmania: Royal Society of Tasmania, Hobart.
Transvaal: Government Library, Pretoria.
Trinidad: Victoria Institute, Port of Spain.
Tunis, via France.
Turkey: American Board of Commissioners for Foreign Missions, Boston.

Uruguay: Oficina de Depósito, Reparto y Canje Internacional, Montevideo.
Venezuela: Biblioteca Nacional, Caracas.
Victoria: Public Library of Victoria, Melbourne.
Western Australia: Public Library of Western Australia, Perth.
Zanzibar. (Sent by mail.)

In conclusion, it is my sad duty to record here the death, on January 27, 1910, of Ferdinand V. Berry, Chief Clerk of the International Exchange Service. Mr. Berry was appointed as clerk January 9, 1884, and became chief clerk of the exchanges on July 1, 1907. During the twenty-six years that Mr. Berry served the Institution his work was faithfully and efficiently performed, and his loss is deeply regretted.

Respectfully submitted.

C. W. SHOEMAKER,
Chief Clerk, International Exchange Service.

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

Appendix IV.

REPORT ON THE NATIONAL ZOOLOGICAL PARK.

Sir: I have the honor to present herewith a report of the operations of the National Zoological Park for the fiscal year ended June 30, 1910.

The appropriation for that year was $95,000, and the estimated amount for current maintenance was $83,706.92, leaving but $11,293.08 from which to make necessary repairs and extensions of buildings, improvements of roads and grounds, and additions to the collection.

The largest sum expended for any one object was that of $5,291, for the transportation of animals from Africa, a detailed account of which is appended hereto. For the accommodation of these animals alterations and additions were made to the buildings already in use. In the extension to the lion house a number of small and comparatively slight cages were removed and six new and larger ones, strong enough to hold lions and other large cats, were built in. The antelope house was enlarged by an extension 50 by 50 feet, thus furnishing ten additional stalls and a much needed new entrance. The building, although very simple in construction, is now admirably adapted for accommodating visitors, having three entrances with convenient approaches. The new stalls or cages are provided with commodious yards, which were nearly completed at the close of the fiscal year.

The first work of the year was the construction of a suitable pool for sea lions and seals, which was established in the wooded valley occupied by the beaver. This pool is 47 by 96 feet, with a depth of 6 feet 3 inches. It has a shelter house of stone, ample banks, and a level border, the whole inclosed with an iron fence.

Two watchman's houses were placed at the park entrance and a flag pole was erected on the hill south of the lion house.

This was all the new work that it was possible to execute from the limited amount available.

Minor improvements and repairs were made as follows: Concrete steps and walk to the bird house; connecting the culvert in the beaver valley with Rock Creek sewer; painting flying cage; surfacing gravel and cinder walks; making a serviceable road to the coal vault of the central heating plant.

Much of this work it has been possible to carry on economically by the use of stone from a quarry in the park and of sand and gravel from the creek.

The following is a tabular statement of the cost of this work:

Alterations to lion house	$1,100.00
Addition to antelope house, with approach	2,500.00
Sea-lion pond, including stonework, concrete construction, fencing, grading, planting, and walk	2,025.00
Two watch houses ($125 each)	250.00
Flag pole	100.00
Steps and walk to bird house	110.00
Culvert and connection	600.00
Repainting flying cage	425.00
Surfacing walks	600.00
Road to coal vault	125.00

AFRICAN ANIMALS.

While the Smithsonian Expedition was in British East Africa Mr. W. N. McMillan, of Nairobi, presented to the park a collection of East African animals which he had gathered at his place, Juja farm, about 25 miles from Nairobi. The collection included 5 lions, 2 cheetahs, a leopard, a Grant's gazelle, a warthog, and several smaller mammals and birds. It was thought advisable to send the assistant superintendent of the park to Nairobi to attend to the shipping and come through with the animals, on account of the importance and value of this collection, and the fact, stated by the Smithsonian party, that other desirable specimens, already in captivity, could be obtained in the region about Nairobi, and also because of the special precautions which the Agricultural Department required to be taken in order to prevent the introduction of contagious diseases, either through the animals themselves or by means of food or other supplies obtained for them. He left Washington toward the end of July, 1909, and returned with the animals December 17. Shipment from Mombasa was made October 28 by a steamer of the Compagnie des Messageries Maritimes. At Port Said the animals were transferred to a lighter and kept there, without landing, for thirteen days, awaiting the arrival of a steamer going directly to Philadelphia. The voyage from Port Said, by a German freight steamer, occupied twenty-six days, but the weather was unusually favorable. With the exception of a few animals, very recently captured or very young, there was no loss between Nairobi and Philadelphia. The ruminants and warthog were held in quarantine at Philadelphia for about six weeks to allow thorough inspection and inoculation tests to be made to determine whether they carried any communicable disease. It is gratifying that all proved to be free from disease, since the region from which they came can furnish many important animals which are as yet but little represented in zoological collections. Through the kindness of the Philadelphia Zoological Society the animals were kept at their gardens during the time of quarantine. The two cheetahs had died before shipment was made and the male Grant's gazelle had been killed by accident. With these exceptions all of the animals presented by Mr. McMillan reached Washington safely and are still at the park. A pair of eland, a pair of Coke's hartebeest, a waterbuck, a Grant's zebra, and a bateleur eagle, which were purchased, reached Philadelphia in apparently good condition, but the male eland died of impaction of the intestine while in quarantine. A young male eland was presented by Lord Delamere, but, being in poor condition when received, lived only a few days. A pair of Thomson's gazelle and an impala, all very young, and a pair of white-bearded gnu, caught just before shipping, also died very soon.

Mr. G. H. Goldfinch, assistant game ranger of British East Africa, presented a hyrax and two specimens of Lophiomys, a rare and little-known rodent.

The 21 animals which reached the United States included 15 species, of which 13 were species or subspecies not at any time before represented in the collection of the park. The lions are of the subspecies known as "Kilimanjaro lion" (*Felis leo sabakiensis*).

In arranging for transportation it was necessary to go to London and Hamburg, and, taking advantage of the opportunity, brief visits were made to 14 zoological gardens in Europe, and the Giza Garden, near Cairo, was visited on the return.

The expenditures in connection with these animals were:

Freight, hauling, and expenses of transshipping	$2,555
Purchase of animals	728
Cages for shipping	450

Food for animals	$520
Transportation and subsistence of A. B. Baker	730
Help with animals, including services of attendants, gratuities to ship's officers, etc	190
Telegraph and cable messages	43
Miscellaneous	75
Total	5,291

Thirty-four species or subspecies new to the collection were exhibited during the year, including:

Kilimanjaro lion.	Defassa waterbuck.	Cape hyrax.
Clouded leopard.	Grant's gazelle.	Short-tailed eagle.
Indian tapir.	Muntjac.	Warlike crested eagle.
East African eland.	Grant's zebra.	
Coke's hartebeest.	Northern warthog.	

The most important losses were:

Indian tapir.	Dromedary.	2 jabirus.
East African eland.	2 llamas.	Whooping crane.
2 Rocky Mountain sheep.	2 jaguars.	North African ostrich.
3 mule deer.	2 Tasmanian wolves.	
Reindeer.	2 leopards.	

One hundred and sixty-two dead animals were sent to the National Museum. Autopsies were made by pathologists of the Bureau of Animal Industry on 99 animals, showing causes of death as follows:

Pneumonia	22	Hydrophilosis	2
Tuberculosis	7	Proteusbacillosis	1
Pulmonary congestion	2	Porocephalus infestation	1
Aspergillosis	5	Septicemia	1
Gastro-enteritis	8	Intestinal parasites	1
Enteritis	12	Enterotoxism	1
Gastritis	7	Psoroptic mange	1
Hemorrhagic enteritis	2	Eversion of rectum	1
Nephritis	3	Traumatism	1
Fatty degeneration of liver	1	Malnutrition from faulty teeth	1
Peritonitis	2	Suffocation	1
Metritis	1	Old age	2
Intestinal coccidiosis	5	No cause found	3
Cercomoniasis	5		

VISITORS.

The number of visitors to the park during the year was 721,555, a daily average of 1,977. This number is an increase over the previous year of 156,816, and an increase in the daily average of 430. The largest number in any month was 156,432, in March, 1910, a daily average for the month of 5,046.

During the year there visited the park 155 schools, Sunday schools, classes, etc., with 3,883 pupils, a monthly average of 324 pupils. While most of them were from the city and immediate vicinity, 34 of the schools were from neighboring States, and classes came from Falmouth and Haverhill, Massachusetts; Stafford Springs, Connecticut; Rochester, Dover, Exeter, and Newport, New Hampshire; Bellows Falls, Vermont; and Sanford, Maine.

Statement of the collection.

Accessions during the year:	
Presented	87
Received in exchange	8
Purchased	139
Deposited	8
Born and hatched in National Zoological Park	64
Captured in National Zoological Park	1
Total	307

PRESENTED.

Rhesus monkey, Miss Justine Ingersoll, Boston, Mass	2
Common macaque:	
William, F. Wenger, Washington, D. C	1
G. R. Tompkins, Warrenton, Va	1
Bonnet macaque, G. R. Tompkins, Warrenton, Va	1
Baboon, W. N. McMillan, Nairobi, British East Africa	1
White-throated capuchin, Roland Davis, Washington, D. C	1
Lion, W. N. McMillan, Nairobi, British East Africa	5
Leopard, W. N. McMillan, Nairobi, British East Africa	1
Bay lynx, Adams Express Co., Washington, D. C	1
Florida lynx, Howard Elliott, Washington, D. C	1
Coyote, R. P. Neuman, Englewood, Kans	2
Gray fox, J. F. Unverzagt, Washington, D. C	1
American otter, Frederic B. Hyde, Washington, D. C	2
Kinkajou, Surg. W. H. Bell, U. S. Navy, Cristobal, Canal Zone	1
Common skunk, F. C. Duehring, Washington, D. C	1
Cinnamon bear, E. S. Bruce, U. S. Forest Service	1
Virginia deer, Thos. Blagden, Washington, D. C	1
Common goat, John R. McLean, Washington, D. C	4
Grant's gazelle, W. N. McMillan, Nairobi, British East Africa	1
Northern warthog, W. N. McMillan, Nairobi, British East Africa	1
Lophiomys, G. H. Goldfinch, Asst. Game Ranger, Nairobi, British East Africa	1
English rabbit:	
Mrs. Birdsall, Washington, D. C	1
Mrs. Street, Washington, D. C	2
Common opossum:	
Charles L. Medley, Victoria, Mo	1
E. Droop, Washington, D. C	2
The President, Washington, D. C	2
D. L. Coon, Washington, D. C	1
Albino opossum, donor unknown	1
Sparrow hawk, Mrs. C. H. McAndrie, Washington, D. C	1
Sharp-shinned hawk, E. L. Burritt, Washington, D. C	1
Red-shouldered hawk, T. Hanlon, Washington, D. C	1
Bald eagle, Col. R. L. Montague, Washington, D. C	1
Warlike crested eagle, W. N. McMillan, Nairobi, British East Africa	1
Hawk, W. N. McMillan, Nairobi, British East Africa	1
Egyptian vulture, W. N. McMillan, Nairobi, British East Africa	1
Pileated vulture, W. N. McMillan, Nairobi, British East Africa	1
Great horned owl:	
John Ricketts, Flinton, Pa	1
Donor unknown	1

Barn owl:	
R. H. Chappell, Washington, D. C	1
Dr. C. N. Lenman, Washington, D. C	1
Screech owl:	
Raymond Campbell, Washington, D. C	1
Mrs. Arthur Lee, Washintgon, D. C	1
Red and yellow and blue macaw, D. S. Sheahan, Washington, D. C	1
Red-shouldered Amazon, Mrs. Bicknell, Washington, D. C	1
Yellow-fronted Amazon, B. Munoz, Honduras	1
Parrakeet:	
Mrs. Leigh Hunt, Bethesda, Md	2
M. B. Tubman, Washington, D. C	1
Common canary:	
M. Doumer, Washington, D. C	1
Mrs. H. C. Steuart, Washington, D. C	1
Cutler Vickery, Washington, D. C	1
Java sparrow, Miss M. Britton, Washington, D. C	4
Jungle fowl, Dr. C. B. Davenport, Cold Spring Harbor, N. Y	2
Wood ibis, A. M. Nicholson, Orlando, Fla	2
Whistling swan, Mrs. Fitzgerald, Washington, D. C	1
Brant, Dr. H. L. Gosling, Washington, D. C	1
Alligator:	
Mark Sloane, Washington, D. C	1
Miss C. Harndon, Washington, D. C	1
Dr. W. S. Harban, Washington, D. C	1
DeF. Larner, Washington, D. C	1
Edgar Shreve, Washington, D. C	1
Mrs. Mary Bartlett, West Milford, W. Va	2
Gila monster, Gustav Friebus, Washington, D. C	1
Rattlesnake, G. H. White, Washington, D. C	1
Black snake:	
W. V. Cox, Washington, D. C	1
Thos. C. Johnson, Deanwood, D. C	1
House snake, Thos. C. Johnson, Deanwood, D. C	1
Garter snake, H. F. Carl, Washington, D. C	1

SUMMARY.

Animals on hand July 1, 1909	1,416
Accessions during the year	307
Total	1,723
Deduct loss (by exchange, death, and returning of animals)	299
On hand June 30, 1910	1,424

	Species.	Individuals.
Mammals	153	625
Birds	184	692
Reptiles	35	107
Total	372	1,424

Respectfully submitted.

FRANK BAKER,
Superintendent.

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

Appendix V.

REPORT ON THE ASTROPHYSICAL OBSERVATORY.

Sir: I have the honor to present the following report on the operations of the Smithsonian Astrophysical Observatory for the year ending June 30, 1910:

EQUIPMENT.

The equipment of the observatory is as follows:

(*a*) At Washington, in an inclosure of about 16,000 square feet, are contained five small frame buildings used for observing and computing purposes, three movable frame shelters covering several out-of-door pieces of apparatus, and also one small brick building containing a storage battery and electrical distribution apparatus.

(*b*) At Mount Wilson, California, upon a leased plot of ground 100 feet square in horizontal projection, are located a one-story cement observing structure, designed especially for solar constant measurements, and also a little frame cottage, 21 feet by 25 feet, built and furnished last September for observer's quarters. It is highly satisfactory to note from the decrease in probable error of the observations secured in 1909 on Mount Wilson, compared with those of previous years, that the new cement observatory there, located as it is far from the dust, smoke, and disturbances of the other parts of the mountain, is excellently adapted for securing the most exact results.

WORK OF THE YEAR.

The present year's results are of uncommon interest, for they appear to fix within narrow limits the value of the solar constant of radiation. When in 1902 the first attempts were made here to measure it, that first-rank constant of nature, the intensity of the solar radiation at the earth's mean distance from the sun, was unknown within the wide range between 1.75 and 4 calories per square centimeter per minute. This range of values is given, with a preference for Langley's value (3 calories), by Hann in his standard work on meteorology, published in 1905.

It is improbable that this observatory would have continued since 1902 in solar-constant work had it not been that the results of 1903 gave strong indications of considerable variability of the sun in short intervals and that later work also strongly supported this presumption. The late director, Secretary Langley, shared, with many others of the most competent judges on the subject, the impression that to determine the solar constant of radiation with any considerable degree of accuracy or certainty was, if not impossible, yet a thing which would probably be long deferred and would involve spectro-bolometric measurements at the highest possible altitudes at which men may exist. He did not at all believe that our results of 1903 approximated to the true value of the solar constant, but only that they might be so far independent of ordinary atmospheric changes as to be used in determining the probability of solar variability. Hence, in 1905, he instructed the present writer to bear in mind, in going to Mount Wilson for the first time, that it was not the solar constant but

the possibility of solar variability which was the result to be determined by the expedition. This inquiry has, indeed, been the primary one in all the subsequent work, but not to the exclusion of attempts to fix the value of the solar constant itself.

There were at that time two principal and seemingly formidable difficulties hindering the determination of the solar constant of radiation. First, there was no instrument capable of absorbing fully and adapted for measuring completely the energy received at the earth's surface, excepting, perhaps, the little-known and rarely used instrument invented by W. A. Michelson, of Russia, about 1894. Second, there was grave doubt if a true estimate of the loss of radiation in traversing the air could be made. Langley has somewhere described the first obstacle as "formidable," the second as "perhaps insurmountable."

As stated in previous reports, much attention was given from 1903 onward to devising a standard pyrheliometer, and thus establishing the absolute scale of radiation measurements. A considerable degree of success seemed to be attained in 1906, but the results obtained in that year were found, by comparison with instruments of the United States Weather Bureau, to differ so much from the generally adopted scale of Ångström that further work, involving finally the construction of two additional water-flow pyrheliometers, was done. The last of these instruments, and by far the most perfect of them all, was completed and tried at Mount Wilson in October, 1909. A fairly close agreement seemed to hold between it and its immediate predecessor, but when the electrical constants of both instruments were determined with extreme care in February, at Washington, by Mr. Aldrich, the gap widened. A source of error, till then little regarded, was reconsidered, and painstaking comparisons of pyrheliometers were carried through at Washington by Messrs. Aldrich, Abbot, and Fowle. These were finished in June, 1910, and the two standard pyrheliometers were found to agree together well within the probable error of the highly accurate experiments. Not only so, but each instrument was found to take up and measure between 99 and 100 per cent of such various quantities of electrically introduced heat as were used as tests. Finally these definite measurements indicated that while the results published at page 46 in volume 2 of the Annals, made with standard pyrheliometer No. 1, are 4 or 5 per cent above the true scale, yet when all the experiments made with that instrument, at Washington as well as Mount Wilson, are collected their mean result is almost in exact agreement with the results obtained in 1910 with standard pyrheliometers Nos. 2 and 3.

It may now be accepted that the absolute scale of radiation is established within three parts in 1,000, and that we may express all our measurements of solar radiation made since 1902 with this degree of accuracy in absolute calories per square centimeter per minute.

Three secondary pyrheliometers, the cost of whose construction after my designs has been defrayed from the Hodgkins Fund, have been standardized and sent to Russia, France, and Italy. Two others have been sold by the Institution to the United States Agricultural Department. Thus steps are being taken to diffuse the standard scale of pyrheliometry. The new scale is about 5.2 per cent above that of new Ångström pyrheliometers.

The second obstacle mentioned above seems now less serious than the first. It was found in 1905 and 1906 that practically identical values of the solar constant resulted from good series of spectro-bolometric observations of the same day taken at Washington (sea level) and Mount Wilson (6,000 feet elevation). But in August, 1909, Mr. Abbot ascended Mount Whitney (14,500 feet) with a complete spectro-bolometric outfit, and, notwithstanding many days of

unpromising weather, succeeded on September 3, under the most perfect sky and in exceptionally dry air, in making a complete and satisfactory series of solar constant measurements. A prism of quartz and two mirrors of magnalium were the only optical parts to affect the rays, so that it was possible to observe from wave length 0.29 μ to wave length 3.0 μ. This extended region includes not only all the visible but the ultra-violet and infra-red spectra, with sufficient completeness to include in the discussion apparently within 1 per cent of all the rays which the sun sends the earth and to make the allowance for rays not observed practically sure. During the same day Mr. Ingersoll observed with the usual complete spectro-bolometric outfit on Mount Wilson, and his results were in accord with what would be expected from his preceding and following day's work there and agreed within 1 per cent with those obtained simultaneously on Mount Whitney.

In view of the agreement of results on the solar constant of radiation obtained at sea level, 1 mile, and 2¾ miles elevation, it now seems highly probable that we can really by Langley's method of homogeneous rays allow for losses in the air and get the same values that we would observe directly if we could take our instruments above the air altogether.

The reduction of spectro-bolographic work to the absolute scale of pyrheliometry enables us to give as the average value of the solar constant of radiation for the epoch 1905 to 1909, 1.924 calories per square centimeter per minute. It is probable that observations at sun-spot minimum will tend to raise this value by rather more than 1 per cent, so that we may suppose the mean value of the solar constant for a complete sun-spot cycle will be about 1.95 calories.

Experiments made in 1909 at Mount Wilson with various optical systems agree within their probable error with one another, and with the results obtained on Mount Whitney in fixing the distribution of energy in the spectrum of the sun outside the atmosphere. In the Mount Whitney work the curve of energy distribution was followed to a wave-length estimated (not very accurately) as 0.29μ and it there practically reached zero intensity, although the quartz and magnalium apparatus would have been capable of transmitting the rays, had they existed, of much shorter wave-lengths. In the spectrum of the "perfect radiator," corresponding to the apparent temperature of the sun, the intensity of the ultra-violet rays would be of some importance for a considerably farther stretch of wave-lengths beyond this. It therefore appears that either the earth's atmosphere, even above Mount Whitney, or else the sun's envelope, effectually hinders the solar rays. If it is the former, then it may be that the above-mentioned value of the solar constant should still be raised a few per cent. But the known powerful selective absorption of vapors in the sun's envelope seems quite reasonably competent alone to produce the observed weakness of the solar spectrum in the ultra-violet. This view is confirmed by experiments of Miethe and Lehmann, who found no extension of the solar spectrum with increasing elevation, although they shifted their observing station from Berlin (50 meters) to Monte Rosa (3,500 meters), thus greatly diminishing the layer of air traversed. Their shortest wave-length was 0.2911μ, closely agreeing with ours.

From our experiments of 1909 the apparent average solar temperature is 6430°, 5840°, or 6200° of the absolute, according as we follow Wien's displacement law, Stefan's law, or Planck's law as the method of computation. But the temperature of the sun, apart from the uncertainty of terms when dealing with such high values, is probably a quantity which has very various values, from the center to the limb of the sun's disk, depending on the depth within the sun at which the radiation originates.

At Washington Messrs. Fowle and Aldrich have continued experiments on the transmission by moist columns of air for long-wave radiation, though with

many interruptions due to the difficulty of the research. The work has been carried to wave-length beyond 15μ in the infra-red, and for columns of air 800 feet long. It is not yet possible to summarize the results.

Messrs. Fowle and Aldrich and Miss Graves have made rapid progress with the reduction of solar-constant work of 1909.

Experiments have been begun for the purpose of devising economical means of utilizing solar energy for domestic purposes.

PERSONNEL.

Dr. L. R. Ingersoll served as temporary bolometric assistant on Mount Wilson to September 6, 1909.

Mr. L. B. Aldrich was given a temporary appointment as bolometric assistant at Washington beginning September 1, 1909. He passed a competitive examination and was reappointed provisionally on January 10, 1910. His appointment was made permanent, to begin July 1, 1910.

SUMMARY.

The work of the year is notable for the determination of the absolute scale of pyrheliometry and for the success of spectrobolometric observations of the solar constant of radiation on Mount Whitney. These agree with simultaneous observations of the same kind on Mount Wilson. Reducing these and other results to the absolute scale of pyrheliometry, we may fix the average value of the solar constant of radiation at 1.925 calories per square centimeter per minute for the epoch 1905–1909. Making allowance for the higher values which must prevail at sun-spot minimum, the solar constant may be estimated at 1.95 calories as an average value for a sun-spot cycle. No reason has been found for departing from the view heretofore held that short-interval variations of 5 per cent or more from this value occur. The energy distribution in the solar spectrum outside the atmosphere has been determined with the bolometer on Mount Whitney between wave lengths 0.29μ in the ultra violet and 3.0μ in the infra red. This region appears to contain full 99 per cent of all the solar energy outside the atmosphere. The apparent temperature of the sun as computed by three different methods comes out 6430°, 5840°, and 6200° of the absolute scale. Researches on the transmission of moist columns of air for long-wave rays, such as the earth emits, have been continued to wave lengths beyond 15μ, and for columns of air 800 feet in length. Secondary pyrheliometers, standardized to the absolute scale, have been sent to Russia, France, and Italy, and also furnished to the United States Weather Bureau and Department of Agriculture.

Respectfully submitted.

C. G. Abbot, *Director.*

Dr. Charles D. Walcott,
Secretary of the Smithsonian Institution.

Appendix VI.

REPORT ON THE LIBRARY.

Sir: I have the honor to present the following report on the operations of the library of the Smithsonian Institution for the fiscal year ending June 30, 1910:

The accessions recorded for the Smithsonian deposit, Library of Congress, numbered 2,653 volumes, 2,879 parts of volumes, 1,396 pamphlets, and 623 charts, making a total of 7,551 publications. The accession numbers run from 495,195 to 500,000. These publications were forwarded to the Library of Congress immediately upon their receipt and entry. In their transmission 270 boxes were required, containing approximately the equivalent of 10,800 volumes. The actual number of pieces sent, including parts of periodicals, pamphlets, and volumes, numbered 36,526. This statement does not, however, include about 2,948 parts of serial publications secured in exchange to complete sets and transmitted separately.

The Institution has continued the policy of sending public documents presented to it to the Library of Congress without stamping or entering. The number of publications given above does not include these, nor does it include other publications for the Library of Congress received through the International Exchange Service.

The libraries of the Smithsonian office, of the Astrophysical Observatory, and the National Zoological Park have received 473 volumes and pamphlets and 253 parts of volumes and charts, making a total of 626 publications, and a grand total, including the publications for the Smithsonian deposit, of 8,177. The actual decrease in the number of publications entered for the Smithsonian library is not as great as would at first appear, owing to the fact that in the present report a statement has been made of the number of completed volumes accessioned, rather than, as was formerly the custom, of the number of parts constituting a volume. Special attention has been given to the checking up and completing of the Smithsonian deposit sets of publications of scientific societies and learned institutions of the world, together with the series of scientific periodicals contained in the library.

The parts of serial publications entered on the card catalogue numbered 26,772, and 1,605 slips for completed volumes were made; 277 cards for new periodicals and annuals, together with 418 donor cards and 1,114 catalogue cards for separate publications were made and filed.

Inaugural dissertations and academic publications were received and accessioned from universities at the following places:

Basel.	Halle an der Saale.	St. Petersburg.
Berkeley.	Leipzig.	Utrecht.
Berlin.	Liege.	Vienna.
Breslau.	Lund.	Würzburg.
Graz.	Paris.	

The establishing of new exchanges and the securing of missing parts to complete sets of publications in the Smithsonian library required the writing of

3,251 letters, resulting in the addition of about 277 periodicals and in the receipt of about 2,948 missing parts.

The library has again cooperated with the International Exchanges in sending to foreign countries lists of government documents and serial publications of that class needed to complete the sets in the Library of Congress. In addition to the countries already enumerated in previous reports, lists have been sent to Natal, New Zealand, Spain, and Venezuela.

The publications in the reading room being in the main of a class not to be found elsewhere, a yearly increase is to be noted in the number of persons consulting them. The readers include scientific workers not only from Washington, but from other American and foreign cities. The staff has withdrawn for office use 52 bound volumes of periodicals and 3,336 parts of scientific periodicals and popular magazines. In addition, the various bureaus of the Government continue to avail themselves of the opportunity to use these publications as well as those in the sectional libraries of the institution.

The mail receipts numbered 43,222 packages, and 7,117 packages were received through the International Exchange Service. The publications contained therein were stamped and distributed for entry from the mail desk. About 5,111 acknowledgments were made on the regular forms in addition to the letters which were written in acknowledgment of publications received in response to the requests of the institution for exchange.

The employees' library.—The books added to this library by purchase numbered 30, and by binding 300 volumes of periodicals were made available for circulation. The total number of books borrowed was 2,092. The sending of a selected number of books from this library to the National Zoological Park has been continued, but the sending of books to the Bureau of American Ethnology was discontinued when the Bureau moved into the Smithsonian building in January, 1910.

Bibliography of aeronautics.—The manuscript for the Bibliography of Aeronautical Literature to July 1, 1909, was completed during the summer of that year, and the work, forming volume 55 of the Smithsonian Miscellaneous Collections, was published during the month of April, 1910. Numerous accessions have been made to the collection of aeronautical literature in the office library. The volumes have been bound and are now available for reference.

At the request of the American committee on cooperation with the International Congress of Archivists and Librarians, the assistant librarian prepared an answer to the question "Dans quel sens y a-t-il lieu de réorganiser et d'étendre le service des échanges internationaux?" The reply was sent in the latter part of January for presentation to the congress convening in Brussels August 27 to 31.

American Historical Association.—The arranging of new exchanges of the annual reports of the American Historical Association from the allotment agreed upon for that purpose has resulted in a number of publications of historical societies throughout the world being added to the Smithsonian deposit at the Library of Congress.

UNITED STATES NATIONAL MUSEUM.

The library of the Museum has suffered from congestion and is handicapped in its work by lack of space. While it has continued to grow during the last ten years, no additional room has been available owing to the overcrowded condition of the Museum building. As the new building is now ready for the collections it will be possible in the near future for the library to have all the room necessary for expansion and proper classification. Many gifts of importance have been received, those deserving special mention being the publications presented

by Dr. Theodore N. Gill, Dr. Charles W. Richmond, Dr. Charles A. White, Dr. E. A. Schwartz, Dr. O. P. Hay, and Dr. Marcus Benjamin. The publications are scientific and of value in completing sets and filling in of the series of authors' separates.

In the death of Dr. Charles A. White the Museum library has lost one of its valued benefactors. Doctor White was at all times ready to forward the interests of the Museum library and gave material assistance in the work of completing its series of authors' separates and its sets of periodical publications. His gifts have been numerous and are of special value along the lines of the work upon which he was engaged.

Lists of the publications in the sectional libraries of the Museum have been made, and an experienced cataloguer has been checking them up with the publications on the shelves in the sections. The work of checking is uncompleted at the close of the fiscal year, but will be continued.

In the Museum library there are now 38,300 volumes, 61,858 unbound papers, and 110 manuscripts. The accessions during the year consisted of 2,056 books, 5,541 pamphlets, and 307 parts of volumes; 1,001 books, 1,055 complete volumes of periodicals, and 6,294 pamphlets were catalogued.

Attention has been given to the preparation of volumes for binding, with the result that 435 books were sent to the government bindery.

The number of books, periodicals, and pamphlets borrowed from the general library amounted to 23,272, including 4,148 from the collections which were assigned to the sectional libraries.

The sectional libraries established in the Museum have remained unchanged, the complete list now standing as follows:

Administration.	Geology.	Mollusks.
Administrative assistant.	History.	Oriental archæology.
Anthropology.	Insects.	Paleobotany.
Biology.	Invertebrate paleontology.	Parasites.
Birds.	Mammals.	Physical anthropology.
Botany.	Marine invertebrates.	Prehistoric archæology.
Comparative anatomy.	Materia medica.	Reptiles.
Editor.	Mesozoic fossils.	Superintendent.
Ethnology.	Mineralogy.	Taxidermy.
Fishes.		Technology.

SUMMARY OF ACCESSIONS.

The following table summarizes all the accessions during the year except for the Bureau of American Ethnology, which is separately administered:

Smithsonian deposit in the Library of Congress, including parts to complete sets	10,499
Office, Astrophysical Observatory, National Zoological Park, and International Exchanges	626
United States National Museum Library	7,904
Total	19,029

Respectfully submitted.

PAUL BROCKETT, *Assistant Librarian.*

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

Appendix VII.

REPORT ON THE INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE.

Sir: I have the honor to submit the following report on the operations of the United States Bureau of the International Catalogue of Scientific Literature for the year ending June 30, 1910.

The International Catalogue of Scientific Literature is an international cooperative enterprise having at present 32 regional bureaus scattered throughout the world, supported by the countries taking part in the work. The duties of these regional bureaus are to collect, index, and classify all contributions to pure science published within the several countries they represent. The material thus prepared is forwarded to the Central Bureau in London, there to be assembled and published.

The catalogue consists of 17 annual volumes, one for each of the following sciences: Mathematics, mechanics, physics, chemistry, astronomy, meteorology, mineralogy, geology, geography, paleontology, general biology, botany, zoology, anatomy, anthropology, physiology, and bacteriology.

The Central Bureau is maintained entirely by the funds received from the subscribers to the catalogue. The regional bureaus are in every case supported by the countries taking part in the enterprise, in the great majority of cases by direct govermental grants.

Since the beginning of the undertaking in 1901 the annual volumes have increased in size to such an extent that the cost of publication at one time exceeded the sum received from subscriptions, and it was necessary to curtail somewhat not only the methods of classifying the various subjects, but also the citation methods used in the subject catalogues. This is now being done without detracting in any way from the value of the catalogue as a work of reference, although the labor of preparation is in most cases much greater.

The allotment for the present fiscal year was $6,000. Five persons are regularly engaged in the Bureau, and occasionally, when funds permit, the assistance of a specialist in some one of the sciences is temporarily employed.

There were 25,082 cards sent from this Bureau during the year as follows:

Literature of 1901	72
Literature of 1902	173
Literature of 1903	248
Literature of 1904	465
Literature of 1905	1,163
Literature of 1906	1,502
Literature of 1907	3,160
Literature of 1908	6,305
Literature of 1909	11,994
Total	25,082

This number does not represent the actual number of citations sent, for on account of a new ruling of the Central Bureau some of the biological cards contained a number of citations each. However, the actual number of cita-

tions has been reduced to approximately 28,000 for the year, which is about 6,000 less than was sent in for the previous year. This decrease is not entirely due to the new methods of classifying, for as the work is each year being brought more nearly up to date fewer old papers are indexed, consequently fewer citations are required. It is estimated that when the work is entirely up to date only about 25,000 citations will be needed to completely index the yearly scientific literature of the United States.

The following-named volumes of the catalogue were received and delivered to the subscribers in this country:

Seventh annual issue: Meteorology, General Biology, Botany, Anatomy, Anthropology, and Bacteriology.

Eighth annual issue: Mathematics, Mechanics, Astronomy, Mineralogy, and Zoology.

For a number of years it has been the aim to eventually prepare this catalogue not only through the cooperation of the various countries, but through direct cooperation of authors and publishers of the papers indexed. This method was actually tried during the present year in the preparation of the volume on zoology, and though it required writing about 517 letters, the result was so satisfactory that it is proposed to gradually extend the method to other sciences.

As has been pointed out before, the London Central Bureau is maintained solely by means of the funds obtained from subscriptions to the catalogue, and the necessary cost of editing and printing is so great that $85 per year has to be charged for the complete set of 17 volumes. This large figure places the work beyond the reach of many who would undoubtedly purchase individual volumes, if not the complete sets. The cost of doubling the edition of the catalogue would be comparatively small, the outlay representing only the cost of press work and paper, and it is felt that if the edition could be doubled and the price reduced one-half, the work could be placed at once within the reach of many small libraries and scientific workers who need such works of reference.

At present the available funds prevent any such course being adopted, but a comparatively small endowment would not only render this move possible, but would enable the present restricted scope of the catalogue to be extended to include at first the applied sciences and then gradually the other records of human progress. A yearly income of $5,000 or $6,000 from a permanent endowment would enable the central bureau to take the necessary steps to first increase the circulation and then broaden the scope of the catalogue, and it is earnestly hoped that in the near future such an endowment may be obtained.

There have been no losses of property during the year, excepting those caused by ordinary wear and deterioration.

In the sundry civil bill approved June 25, 1910, $7,500 was appropriated to carry on the work for the fiscal year ending June 30, 1911. This sum is an increase of $1,500 over the appropriation of the present year.

Respectfully submitted.

LEONARD C. GUNNELL,
Chief Assistant.

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

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Appendix VIII.

REPORT ON THE PUBLICATIONS.

Sir: I have the honor to submit the following report on the publications of the Smithsonian Institution and its branches during the fiscal year ending June 30, 1910:

There was distributed a total of 801 volumes and separates in the series of Smithsonian Contributions to Knowledge, 17,560 in the series of Smithsonian Miscellaneous Collections, 28,879 in the series of Smithsonian Annual Reports, and 2,179 in the series of Special Publications. In addition, there were 959 publications not included in the Smithsonian series distributed by the Institution, and 5,274 publications of the Bureau of American Ethnology sent out during the six months from January 1 to June 30, 1910. This makes a grand total of 55,652, an increase of 11,489 over the previous year.

I. SMITHSONIAN CONTRIBUTIONS TO KNOWLEDGE.

No memoirs of the series of Smithsonian Contributions to Knowledge were issued during the year, although progress was made in preparing for press the Langley Memoir on Mechanical Flight which was begun by the late Secretary Langley in 1904 and continued by Mr. Charles M. Manly, assistant in charge of experiments.

II. SMITHSONIAN MISCELLANEOUS COLLECTIONS.

In the series of Smithsonian Miscellaneous Collections there were published during the year (1) fifteen papers in the Quarterly Issue, which was discontinued December 31, 1909, completing volume 52 of the regular series; (2) one paper in volume 51; (3) seven papers in volume 54, completing that volume; (4) volume 55, Bibliography of Aeronautics; (5) and seven papers in volume 56. The Quarterly Issue papers were as follows:

1872. Smithsonian Miscellaneous Collections. Volume 52, part 4 (Quarterly Issue, vol. 5, part 4) containing Publications, 1873 to 1887. Published January 20, 1910. Octavo. Pages viii, 403–514, with plates 38 to 66. (The Quarterly Issue ends with this volume.)

1873. Prehistoric Ruins of the Gila Valley. By J. Walter Fewkes. Published August 4, 1909. Octavo. Pages 403 to 436, with Plates 38 to 42.

1874. Description of a New Frog from the Philippine Islands. By Leonhard Stejneger, Curator, Division of Reptiles and Batrachians, U. S. National Museum. Published August 4, 1909. Octavo. Pages 437–439.

1875. A New Genus of Fossil Cetaceans from Santa Cruz Territory, Patagonia; and Description of a Mandible and Vertebræ of Prosqualodon. By Frederick W. True, Head Curator of Biology, U. S. National Museum. Published August 7, 1909. Octavo. Pages 441–456, with Plates 43 to 45.

1876. Notes on Certain Features of the Life of the Alaskan Freshwater Sculpin. By Barton A. Bean and Alfred C. Weed, of the Division of Fishes, U. S. National Museum. Published August 19, 1909. Octavo. Pages 457–460.

1877. The Geologic Work of Mangroves in Southern Florida. By T. Wayland Vaughan, Custodian of Madreporarian Corals, U. S. National Museum; Supervising Geologist in Charge of Coastal Plain Investigations, U. S. Geological Survey. Published September 15, 1909. Octavo. Pages 461–464, with Plates 46 to 52.

1878. Crystallographic Notes on Calcite. By J. E. Pogue, Assistant Curator, Division of Mineralogy, U. S. National Museum. Published September 24, 1909. Octavo. Pages 465–468, with Plates 53 and 54.

1879. A New Rodent of the Genus Georychus. By Edmund Heller, Field Naturalist, Smithsonian African Expedition. Published September 24, 1909. Octavo. Pages 469–470, with Plate 55.

1880. Two New Rodents from British East Africa. By Edmund Heller, Field Naturalist, Smithsonian African Expedition. Published November 13, 1909. Pages 471–472, with Plate 56.

1881. A Heretofore Undescribed Stony Meteorite from Thomson, McDuffie County, Georgia. By George P. Merrill, Head Curator, Department of Geology, U. S. National Museum. Published December 2, 1909. Octavo. Pages 473–476. Plates 57 and 58.

1882. On a Remarkable Cube of Pyrite Carrying Crystallized Gold and Galena of Unusual Habit. By Joseph E. Pogue, Assistant Curator, Division of Mineralogy, U. S. National Museum. Published December 22, 1909. Octavo. Pages 477–484, with Plate 59.

1883. A New Carnivore of British East Africa. By Gerrit S. Miller, jr., Curator, Division of Mammals, U. S. National Museum. Published December 18, 1909. Octavo. Pages 485–487, with Plates 60 to 62.

1884. Description of Fossil Plants from the Mesozoic and Cenozoic of North America. I. By F. H. Knowlton. Published January 11, 1910. Octavo. Pages 489–496, with Plates 63 and 64.

1885. Two New Genera of Murine Rodents. By Gerrit S. Miller, jr., Curator, Division of Mammals, U. S. National Museum. Published January 12, 1910. Octavo. Pages 497–498.

1886. A Shelter for Observers on Mount Whitney. By C. G. Abbot, Director of the Smithsonian Astrophysical Observatory. Published January 12, 1910. Octavo. Pages 499–506, with Plates 65 and 66.

1887. List of Publications, continued from list in Quarterly Issue, volume 5, part 3. Published January 21, 1910. Octavo. Pages 507–509.

In the regular series of Smithsonian Miscellaneous Collections the following were published, during the year:

1869. The Mechanics of the Earth's Atmosphere (a collection of translations). Third Collection. By Cleveland Abbe. Hodgkins Fund. Published 1909. Octavo. Pages IV, 617. Volume 51, Number 4.

1870. Landmarks of Botanical History, Part I, Prior to 1562 A. D. By Edward L. Greene. Published 1909. Octavo. Pages 329. Part of volume 54.

1920. Bibliography of Aeronautics. By Paul Brockett. Hodgkins Fund. Published 1910. Octavo. Pages XIV, 940. Volume 55.

1922. Development of the Brain of the American Alligator; The Paraphysis and Hypophysis. By Albert M. Reese. Published March 1, 1910. Octavo. Pages 20, with 5 plates. Volume 54, Number 2.

1923. Constants of Nature. Part 5, A Recalculation of Atomic Weights. Third edition. By Frank Wigglesworth Clarke. Published May 6, 1910. Octavo. Pages IV, 548. Volume 54, Number 3.

1924. Five New Rodents from British East Africa. By Edmund Heller. Published February 28, 1910. Octavo. Pages 2+4, with 2 plates. Volume 54, Number 4.

1925. A New Rodent of the Genus Saccostomus from British East Africa. By Gerrit S. Miller, jr. Published February 28, 1910. Octavo. Pages 2+2, with 1 plate. Volume 54, Number 5.

1926. A New Sable Antelope from British East Africa. By Edmund Heller. Published March 3, 1910. Octavo. Pages 2+2. Volume 54, Number 6.

1927. Description of a New Species of Hippopotamus. By Gerrit S. Miller, jr. Published March 28, 1910. Octavo. Pages 2+3, with 4 plates. Volume 54, Number 7.

1929. The Scales of the African Characinid Fishes. By T. D. A. Cockerell. Published May 7, 1910. Octavo. Pages 2+10, with 2 plates. Volume 56, Number 1.

1930. Mammals Collected by John J. White in British East Africa. By N. Hollister. Published March 31, 1910. Octavo. Pages 2+12, with 2 plates. Volume 56, Number 2.

1931. The Scales of the Mormyrid Fishes, with Remarks on Albula and Elops. By T. D. A. Cockerell. Published May 7, 1910. Pages 2+4. Volume 56, Number 3.

1933. Upper Yukon Native Customs and Folk-Lore. By Ferdinand Schmitter. Published May 26, 1910. Octavo. Pages 2+30. Volume 56, Number 4.

1935. A Preliminary Study of Chemical Denudation. By Frank Wigglesworth Clarke. Published June 29, 1910. Octavo. Pages 2+19. Volume 56. Number 5.

1936. The Age of the Earth. By George F. Becker. Published June 29, 1910. Octavo. Pages 2+28. Volume 56, Number 6.

1937. Description of a New Subspecies of African Monkey of the Genus Cercopithecus. By D. G. Elliot. Publishd June 11, 1910. Octavo. Pages 2+1. Volume 56, Number 7.

Of the regular series of Smithsonian Miscellaneous Collections in press at the close of the year, there were:

1934. Cambrian Geology and Paleontology. Number 6: Olenellus and other Genera of the Mesonacidæ. By Charles D. Walcott. Volume 53, Number 6.

1939. Cambrian Geology and Paleontology. Number 7: Pre-Cambrian Rocks of the Bow River Valley, Alberta, Canada. By Charles D. Walcott. Volume 53, Number 7.

1940. Cambrian Geology and Paleontology. II. Abrupt Appearance of the Cambrian Fauna on the North American Continent. By Charles D. Walcott. Volume 57, Number 1.

1941. Notes on a Horn-feeding Lepidopterous Larva from Africa. By August Busck. Volume 56, Number 8.

III. SMITHSONIAN ANNUAL REPORTS.

The Annual Report for 1908, though partly in type at the beginning of the fiscal year, was not published until late in the fall.

1917. Annual Report of the Board of Regents of the Smithsonian Institution, showing Operations, Expenditures, and Conditions of the Institution for the year ending June 30, 1908. Octavo. Pages x, 801, with 101 plates. Containing publications 1855, 1856, and 1888 to 1914.

The following papers, forming the General Appendix of the Annual Report of the Board of Regents for 1908, were issued in pamphlet form:

1888. The Present Status of Military Aeronautics. By Maj. George O. Squier, U. S. Army. Pages 117–144, with 23 plates.

1889. Aviation in France in 1908. By Pierre-Roger Jourdain. Pages 145–159.

1890. Wireless Telephony. By R. A. Fessenden. Pages 161–195, with 20 plates.
1891. Phototelegraphy. By Henri Armagnat. Pages 197–207.
1892. The Gramophone and the Mechanical Recording and Reproduction of Musical Sounds. By Lovell W. Reddie. Pages 209 to 231, with 2 plates.
1893. On the Light Thrown by Recent Investigation on Electricity on the Relation between Matter and Ether. By J. J. Thomson. Pages 233–244.
1894. Development of General and Physical Chemistry During the Last Forty Years. By W. Nernst. Pages 245–253.
1895. Development of Technological Chemistry During the Last Forty Years. By O. H. Witt. Pages 255–262.
1896. Twenty Years' Progress in Explosives. By Oscar Guttmann. Pages 263–300, with 9 plates.
1897. Recent Research in the Structure of the Universe. By J. C. Kapteyn. Pages 301–319.
1898. Solar Vortices and Magnetism in Sun Spots. By C. G. Abbot. Pages 321–338, with 5 plates.
1899. Climatic Variations: Their Extent and Causes. By J. W. Gregory. Pages 339–354.
1900. Uranium and Geology. By Prof. John Joly. Pages 355–384, with 1 plate.
1901. An Outline Review of the Geology of Peru. By George I. Adams. Pages 385–430, with 5 plates.
1902. Our Present Knowledge of the Earth. By E. Wiechert. Pages 431–449.
1903. The Antarctic Question—Voyages to the South Pole since 1898. By J. Machat. Pages 451–480, with 1 plate.
1904. Some Geographical Aspects of the Nile. By Capt. H. G. Lyons. Pages 481–503, with 5 plates.
1905. Heredity, and the Origin of Species. By Daniel Trembly MacDougal. Pages 505–523, with 1 plate.
1906. Cactaceæ of Northeastern and Central Mexico, together with a Synopsis of the Principal Mexican Genera. By William Edwin Safford. Pages 525–563, with 15 plates. (A separate edition with index was also published.)
1907. Angler Fishes: Their Kinds and Ways. By Theodore Gill. Pages 565–615.
1908. The Birds of India. By Douglas Dewar. Pages 617–639.
1909. The Evolution of the Elephant. By Richard S. Lull. Pages 641–675, with 2 plates.
1910. Excavations at Boghaz-Keui in the Summer of 1907. By Hugo Winckler and O. Puchstein. Pages 677–696, with 10 plates.
1911. Malaria in Greece. By Ronald Ross. Pages 697–710.
1912. Carl von Linnè as a Geologist. By A. G. Nathorst. Pages 711–743.
1913. Life and Work of Lord Kelvin. The Kelvin Lecture. By Sylvanus P. Thompson. Pages 745–768, with 1 plate.
1914. The Work of Henri Becquerel. By André Broca. Pages 769–785, with 1 plate.

The report of the executive committee and Proceedings of the Board of Regents of the Institution, as well as the report of the Secretary, for the fiscal year ending June 30, 1909, both forming part of the annual report of the Board of Regents to Congress, was printed in pamphlet form and published at the December meeting of the Board of Regents, as follows:

1915. Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1909. Pages iii, 95.
1916. Report of the Executive Committee and Proceedings of the Board of Regents for the year ending June 30, 1909. Pages 19.

The Smithsonian Report for 1909 was partly in type at the close of the fiscal year. In the General Appendix are the following papers:

The Future of Mathematics, by Henri Poincaré.
What Constitutes Superiority in an Airship, by Paul Renard.
Researches in Radiotelegraphy, by J. A. Fleming.
Recent Progress in Physics, by Sir J. J. Thomson.
Production of Low Temperatures, and Refrigeration, by L. Marchis.
The Nitrogen Question from the Military Standpoint, by Charles E. Munroe.
Simon Newcomb, by Ormond Stone.
Solar-radiation Researches by Jules César Janssen, by H. de la Baume Pluvinel.
The Return of Halley's Comet, by W. W. Campbell.
The Upper Air, by E. Gold and W. A. Harwood.
The Formation, Growth, and Habit of Crystals, by Paul Gaubert.
The Distribution of Elements in Igneous Rocks, by Henry S. Washington.
The Mechanism of Volcanic Action, by H. J. Johnston-Lavis.
Conservation of Natural Resources, by James Douglas.
The Antarctic Land of Victoria, by Maurice Zimmermann.
Some Results of the British Antarctic Expedition, 1907–9, by E. H. Shackleton.
The Oceanography of the Sea of Greenland, by D. Damas.
From the Niger, by Lake Chad, to the Nile, by Lieut. Boyd Alexander.
Mesopotamia: Past, Present, and Future, by Sir William Willcocks.
Albert Gaudry and the Evolution of the Animal Kingdom, by Ph. Glangeaud.
Charles Darwin, by August Weismann.
Present Problems in Plant Ecology: Problems of Local Distribution in Arid Regions, by Volney M. Spalding.
The Instinct of Self-concealment and the Choice of Colors in the Crustacea, by Romuald Minkiewicz.
The Origin and Development of Parasitical Habits in the Cuculidæ, by C. L. Barrett.
Some Remarks on the Protective Resemblance of South African Birds, by Alwin Haagner.
An Inquiry into the History of the Current English Names of North American Land Birds, by Spencer Trotter.
Condition of Wild Life in Alaska, by Madison Grant.
Recent Discoveries Bearing on the Antiquity of Man in Europe, by George Grant MacCurdy.
European Population of the United States, by W. Z. Ripley.
The Republic of Panama and its People, by Eleanor Yorke Bell.
Cerámic Decoration: Its Evolution and Applications, by Louis Franchet.
Some Notes on Roman Architecture, by F. T. Baggallay.
The Relation of Science to Human Life, by Adam Sedgwick.
Intellectual Work among the Blind, by Pierre Villey.
The Relation of Mosquitoes, Flies, Ticks, Fleas, and other Arthropods to Pathology, by G. Marotel.
Natural Resistance to Infectious Disease and its Reinforcement, by Simon Flexner.

IV. SPECIAL PUBLICATIONS.

Only one special publication, in the form of a small pamphlet, was issued during the year:

The Smithsonian Institution, at Washington, for the Increase and Diffusion of Knowledge among Men.

There were two special publications nearly ready at the close of the year:

1932. Classified List of Smithsonian Publications available for distribution May, 1910.

1938. Opinions Rendered by the International Commission on Zoological Nomenclature, Opinions 1 to 25.

V. PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM.

The publications of the National Museum are: (*a*) The annual report, forming a separate volume of the report to Congress by the Board of Regents of the Smithsonian Institution; (*b*) the Proceedings of the United States National Museum; (*c*) the Bulletin of the United States National Museum; and (*d*) the Contributions from the United States National Herbarium. The editorship of these publications is in charge of Dr. Marcus Benjamin.

The publications issued during the year are enumerated in the report on the National Museum. These included volume 37 of the Proceedings, containing Museum papers numbered 1695 to 1724, and volume 38, papers numbered 1725–1749.

Eight Bulletins were issued, as follows:

No. 65. Dendroid Graptolites of the Niagaran Dolomites at Hamilton, Ontario. By Ray S. Bassler.

No. 66. A Monographic Revision of the Twisted Winged Insects comprising the Order Strepsiptera Kirby. By W. Dwight Pierce.

No. 67. Directions for Collection and Preserving Insects. By Nathan Banks.

No. 68. A Monograph of West American Pyramidellid Mollusks. By William Healy Dall and Paul Bartsch.

No. 69. The Tænioid Cestodes of North American Birds. By Brayton Howard Ransom.

No. 70. The National Gallery of Art, Department of Fine Arts of the National Museum. By Richard Rathbun.

No. 71. A Monograph of the Foraminifera of the North Pacific Ocean. Part I, Astrorhizidæ and Lituolidæ. By Joseph Augustine Cushman.

No. 72. Catalogue of Nearctic Spiders. By Nathan Banks.

In the series of Contributions from the National Herbarium there appeared:

Volume 12, Part 10. Miscellaneous papers, by J. N. Rose, N. L. Britton, John M. Coulter, and G. N. Collins.

Volume 13, Part 2. Three New Species of Echeveria, by J. N. Rose and J. A. Purpus.

Volume 13, Part 3. The Grasses of Alaska, by F. Lamson-Scribner and Elmer D. Merrill.

Volume 13, Part 4. New or Noteworthy Plants from Colombia and Central America—2, by Henry Pittier.

Volume 13, Part 5. Relationships of the Ivory Palms, by O. F. Cook.

Volume 14, Part 1. The Lichens of Minnesota, by Bruce Fink.

Preliminary pages and index of volume 12, Systematic Investigations and Bibliography.

VI. PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY.

The publications of the Bureau are discussed in detail in another appendix of the Secretary's report. The editorial work is in charge of Mr. J. G. Gurley. The following five bulletins were published by the Bureau during the year:

Bulletin 38. Unwritten Literature of Hawaii. The sacred songs of the Hula, compiled and translated, with notes and an account of the Hula, by Nathaniel B. Emerson, A. M., M. D. 1909. Octavo. Pages 288, with 24 plates, 3 figures, and 14 musical pieces.

Bulletin 39. Tlingit Myths and Texts, by John R. Swanton. 1909. Octavo. Pages VIII, 451.

Bulletin 41. Antiquities of the Mesa Verde National Park: Spruce-Tree House, by J. Walter Fewkes. 1909. Octavo. Pages VIII, 57, with 21 plates and 37 figures.

Bulletin 48. The Choctaw of Bayou Lacombe, St. Tammany Parish, Louisiana, by David I. Bushnell, jr. 1909. Octavo. Pages 37, with 22 plates and 1 figure.

Bulletin 49. List of the publications of the Bureau of American Ethnology, with index to authors and titles. 1910. Octavo. Pages 32.

VII. PUBLICATIONS OF THE SMITHSONIAN ASTROPHYSICAL OBSERVATORY.

There were no new publications issued by the Astrophysical Observatory during the year.

VIII. AMERICAN HISTORICAL ASSOCIATION.

The manuscript of Volumes I and II of the Annual Report of the American Historical Association for 1907 was sent to the Public Printer on September 10, 1908, and the volumes were published in July, 1909.

Volume I contained the following papers:

Report of the Proceedings of the Twenty-third Annual Meeting of the American Historical Association, by Charles H. Haskins, corresponding secretary.

Report of the Proceedings of the Pacific Coast Branch, by Clyde A. Duniway.

Report of Conference on the Relation of Geography and History, by Frederick J. Turner.

Report of Conference on the Work of State and Local Historical Societies, by Evarts B. Greene.

Reports on special conferences on Mediæval European History, on Modern European History, on Oriental History and Politics, on American Constitutional History, and on United States History since 1865, by the respective chairmen of the conferences.

Proposals for an Indian State, 1778–1878, by Annie H. Abel.

The Pacific Railroads and the Disappearance of the Frontier in America, by Frederic L. Paxson.

The Sentiment of the People of California with Respect to the Civil War, by John J. Earle.

The Relation of the U. S. to Latin America, by Bernard Moses;

Legazpi and Philippine Colonization, by James A. Robertson;

Report of the Public Archives Commission;

Francisco de Miranda and the Revolutionizing of Spanish America, by William S. Robertson.

Volume 2 contained the report of the Historical Manuscripts Commission, comprising Diplomatic Archives of the Republic of Texas, I, edited by George P. Garrison.

The manuscript of Volume I of the report for 1908 was sent to the printer on June 17, 1909, and the manuscript of Volume II was received from the secretary of the association and sent to the Public Printer in April, 1910, but neither volume had been completed at the close of the fiscal year.

IX. DAUGHTERS OF THE AMERICAN REVOLUTION.

The manuscript of the annual report of the National Society of the Daughters of the American Revolution for the year ending October 11, 1909, was received on April 18, 1910, and communicated to Congress in accordance with the act of incorporation of that society.

X. SMITHSONIAN ADVISORY COMMITTEE ON PRINTING AND PUBLICATION.

The editor has continued to serve as secretary of the Smithsonian advisory committee on printing and publication. To this committee have been referred the manuscripts proposed for publication by the various branches of the Institution as well as those offered for printing in the Smithsonian Miscellaneous Collections. The committee also considered forms of routine blanks and various matters pertaining to printing and publication, including the qualities of paper suitable for text and plates. Twenty-five meetings were held and 106 manuscripts were acted upon.

Respectfully submitted.

A. HOWARD CLARK, *Editor.*

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION

For the Year Ending June 30, 1910.

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds, receipts, and disbursements of the Institution, and a statement of the appropriations by Congress for the National Museum, the International Exchanges, the Bureau of American Ethnology, the National Zoological Park, the Astrophysical Observatory, and the International Catalogue of Scientific Literature for the year ending June 30, 1910, together with balances of previous appropriations.

SMITHSONIAN INSTITUTION.

Condition of the fund July 1, 1910.

The permanent fund of the Institution and the sources from which it has been derived are as follows:

DEPOSITED IN THE TREASURY OF THE UNITED STATES.

Bequest of Smithson, 1846		$515,169.00
Residuary legacy of Smithson, 1867		26,210.63
Deposit from savings of income, 1867		108,620.37
Bequest of James Hamilton, 1875	$1,000.00	
Accumulated interest on Hamilton fund, 1895	1,000.00	
		2,000.00
Bequest of Simeon Habel, 1880		500.00
Deposits from proceeds of sale of bonds, 1881		51,500.00
Gift of Thomas G. Hodgkins, 1891		200,000.00
Part of residuary legacy of Thomas G. Hodgkins, 1894		8,000.00
Deposit from savings of income, 1903		25,000.00
Residuary legacy of Thomas G. Hodgkins		7,918.69
Total amount of fund in the United States Treasury		944,918.69

OTHER RESOURCES.

Registered and guaranteed bonds of the West Shore Railroad Company, part of legacy of Thomas G. Hodgkins (par value)	$42,000.00
Total permanent fund	986,918.69

Also four small pieces of real estate bequeathed by Robert Stanton Avery, of Washington, D. C.

That part of the fund deposited in the Treasury of the United States bears interest at 6 per cent per annum under the provisions of the act of August 10, 1846, organizing the Institution, and act of Congress approved March 12, 1894. The rate of interest on the West Shore Railroad bonds is 4 per cent per annum. The real estate received from Robert Stanton Avery is exempt from taxation and yields only a nominal revenue from rentals.

Statement of receipts and disbursements from July 1, 1909, to June 30, 1910.

RECEIPTS.

Cash on deposit July 1, 1909		$32,176.70
Interest on fund deposited in United States Treasury, due July 1, 1909, and January 1, 1910	$56,695.12	
Interest on West Shore Railroad bonds to January 1, 1910	1,680.00	
Repayments, rentals, publications, etc	5,877.61	
Contributions from various sources for specific purposes	43,230.95	
		107,483.68
		139,660.38

DISBURSEMENTS.

Buildings, care and repairs		$4,701.28
Furniture and fixtures		420.75
General expenses:		
Salaries	$14,125.86	
Meetings	237.00	
Stationery	745.60	
Postage, telegraph, and telephone	459.96	
Freight	29.97	
Incidentals	1,066.93	
Garage	1,899.75	
Fuel and lights	180.03	
		18,745.10
Library		2,055.50
Publications and their distribution:		
Miscellaneous collections	5,262.61	
Reports	544.07	
Special publications	26.75	
Publication supplies	214.50	
Salaries	6,092.34	
		12,140.27
Explorations, researches, and collections		54,004.03
Hodgkins specific fund, researches and publications		6,301.08
International Exchanges		4,761.74
Legal expenses		100.00

Gallery of Art	$215.75
Advances for field expenses	850.00
	104,295.50
Balance June 30, 1910, deposited with the Treasurer of the United States	35,364.88
	139,660.38

By authority, your executive committee again employed Mr. William L. Yaeger, a public accountant of this city, to audit the receipts and disbursements of the Smithsonian Institution during the period covered by this report. The following certificate of examination supports the foregoing statement, and is hereby approved:

402 WESTORY BUILDING,
Washington, D. C., August 15, 1910.

EXECUTIVE COMMITTEE, BOARD OF REGENTS,
Smithsonian Institution.

SIRS: I have examined the accounts and vouchers of the Smithsonian Institution for the fiscal year ending June 30, 1910, and certify the following to be a correct statement:

Total receipts	$107,483.68
Total disbursements	104,295.50
Receipts exceed disbursements	3,188.18
Amount from July 1, 1909	32,176.70
Balance on hand June 30, 1910	35,364.88
Balance shown by Treasury statement June 30, 1910	39,016.94
Less outstanding checks	3,652.06
True balance June 30, 1910	35,364.88

The vouchers representing payments from the Smithsonian income during the year, each of which bears the approval of the Secretary, or, in his absence, of the Acting Secretary, and a certificate that the materials and services were applied to the purposes of the Institution, have been examined in connection with the books of the Institution and agree with them.

WILLIAM L. YAEGER,
Public Accountant and Auditor.

All moneys received by the Smithsonian Institution from interest, sales, refunding of moneys temporarily advanced, or otherwise, are deposited with the Treasurer of the United States to the credit of the Institution, and all payments are made by checks signed by the secretary.

The expenditures made by the disbursing agent of the Institution and audited by the Auditor for the State and other Departments are reported in detail to Congress, and will be found in the printed document.

Your committee also presents the following summary of appropriations for the fiscal year 1910, intrusted by Congress to the care of the Smithsonian Institution, balances of previous appropriations

at the beginning of the fiscal year, and amounts unexpended on June 30, 1910:

	Available after July 1, 1909.	Balance June 30, 1910.
Appropriations committed by Congress to care of the Institution:		
International Exchanges, 1908	$1.17	[a] $1.17
International Exchanges, 1909	2,232.17	.34
International Exchanges, 1910	32,000.00	5,506.23
American Ethnology, 1908	1.78	[a] 1.78
American Ethnology, 1909	1,175.47	1.15
American Ethnology, 1910	43,000.00	3,890.50
Astrophysical Observatory, 1908	81.19	[a] 81.19
Astrophysical Observatory, 1909	1,571.01	314.50
Astrophysical Observatory, 1910	13,000.00	699.01
International Catalogue, 1908	6.44	[a] 6.44
International Catalogue, 1909	75.11	2.97
International Catalogue, 1910	6,000.00	212.51
Ruin of Casa Grande, 1908	7.98	[a] 7.98
National Museum—		
Furniture and fixtures, 1908	30.98	[a] 30.98
Furniture and fixtures, 1909	22,397.16	66.61
Furniture and fixtures, 1910	200,000.00	87,885.97
Heating and lighting, 1908	43.80	[a] 43.80
Heating and lighting, 1909	2,967.48	137.16
Heating and lighting, 1910	60,000.00	14,526.90
Preservation of collections, 1908	496.78	[a] 446.17
Preservation of collections, 1909	4,869.31	322.30
Preservation of collections, 1910	250,000.00	23,790.15
Books, 1908	92.21	[a] 58.77
Books, 1909	1,083.34	77.05
Books, 1910	2,000.00	1,302.08
Postage, 1910	500.00	.....
Building repairs, 1908	5.83	[a] 5.83
Building repairs, 1909	6,028.68	26.62
Building repairs, 1910	15,000.00	6,486.30
Rent of workshops, 1908	.08	[a] .08
Rent of workshops, 1909	.09	.09
Transfer of Greenough statue of Washington	409.74	409.74
Temporary occupancy of government buildings for tuberculosis congress	15,678.92	15,678.92
Moving collections, etc., to new building [b]	4,000.00	24.73
National Zoological Park, 1908	11.41	[a] 11.18
National Zoological Park, 1909	2,443.69	13.25
National Zoological Park, 1910	95,000.00	5,276.60

[a] Carried to credit of surplus fund.
[b] Act of March 4, 1909, immediately available.

Statement of income from the Smithsonian fund and other revenues, accrued and prospective, available during the fiscal year ending June 30, 1911.

Balance June 30, 1910		$35,364.88
Interest on fund deposited in U. S. Treasury, due July 1, 1910, and January 1, 1911	$56,695.00	
Interest on West Shore Railroad bonds, due July 1, 1910, and January 1, 1911	1,680.00	
Exchange repayments, sale of publications, rentals, etc	5,600.00	
Deposits for specific purposes	8,000.00	
		71,975.00
Total available for year ending June 30, 1911		107,339.88

Respectfully submitted.

J. B. HENDERSON,
JOHN DALZELL,
Executive Committee.

WASHINGTON, D. C., *November 25, 1910.*

PROCEEDINGS OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDING JUNE 30, 1910.

At a meeting of the Board of Regents held February 10, 1909, the following resolution was adopted:

Resolved, That hereafter the Board of Regents of the Smithsonian Institution shall hold their annual meeting on the Tuesday after the second Monday in December, and another meeting on the second Thursday in February.

In accordance with this resolution the board met at 10 o'clock a. m. on December 14, 1909, and on February 10, 1910.

ANNUAL MEETING, DECEMBER 14, 1909.

Present: Hon. Melville W. Fuller, Chief Justice of the United States (chancellor) in the chair; Hon. James S. Sherman, Vice-President of the United States; Senator Shelby M. Cullom; Senator Henry Cabot Lodge; Senator Augustus O. Bacon; Representative John Dalzell; Representative James R. Mann; Dr. James B. Angell; Dr. Andrew D. White; Dr. Alexander Graham Bell; Mr. Charles F. Choate, jr., and the secretary, Mr. Charles D. Walcott.

RESOLUTION RELATIVE TO INCOME AND EXPENDITURE.

Doctor Bell offered the following resolution, which was adopted:

Resolved, That the income of the Institution for the fiscal year ending June 30, 1911, be appropriated for the service of the Institution, to be expended by the secretary, with the advice of the executive committee, with full discretion on the part of the secretary as to items.

ANNUAL REPORT OF THE EXECUTIVE COMMITTEE.

Doctor Bell presented the report of the executive committee for the fiscal year ending June 30, 1909, which, on motion, was adopted.

PERMANENT COMMITTEE.

In behalf of the permanent committee Doctor Bell reported concerning the Andrews estate that since the last annual meeting a writ of error had been allowed by Mr. Justice Peckham, of the Supreme Court of the United States, to the supreme court of the State of New

York, on the ground that the court of appeals did not give full faith and credit to the constitution of Ohio, in respect to prohibiting the general assembly of that State from passing such acts conferring corporate powers. The Supreme Court of the United States decided against the contention of the Smithsonian counsel, under date of May 17, 1909.

Doctor Bell also reported that no change had occurred in the conditions existing in connection with the Avery estate and the Sprague and Reid bequests at the time of the last report.

On motion the report was accepted.

ANNUAL REPORT OF THE SECRETARY.

The secretary submitted his report for the fiscal year ending June 30, 1909, explaining that it had been transmitted to the members of the board prior to this meeting.

On motion the report was accepted.

THE LANGLEY MEDAL.

The secretary stated that at the meeting of the board held February 10, 1909, the Langley medal had been awarded to Messrs. Wilbur and Orville Wright. Notification of this action was transmitted to them in France through the American ambassador, and the following acknowledgment was received:

PAU, *March 15, 1909.*

DEAR SIR: We have received through the American ambassador, Mr. White, your letter of February 18, 1909, informing us of the action of the Board of Regents awarding to us the Langley medal. The honor of such recognition at the hands of an institution of such high standing and unique character is one which we naturally appreciate most highly.

We beg that you will communicate to the board our very sincere thanks and remain,

Yours truly,

WILBUR WRIGHT.
ORVILLE WRIGHT.

Mr. CHAS. D. WALCOTT,
Washington, D. C.

The secretary added that the Wright brothers had accepted an invitation to be present at the board meeting of February 10, 1910, and receive these medals in person.

THE LANGLEY MEMORIAL TABLET.

The secretary said that at a previous meeting Senator Bacon suggested that a tablet in memory of Secretary Langley be erected in a suitable portion of the Smithsonian building, and the board had requested a report upon the subject.

He presented a report which contained a recommendation that a committee be appointed with power to select the tablet and assign a

position for it. On motion, the recommendation was adopted, and the chancellor appointed as the committee Senator Lodge, Senator Bacon, and Secretary Walcott.

B STREET MARKET PLACE.

The secretary said: "The board adopted a resolution in relation to the objectionable features incident to the use of B street north of the National Museum as a market place. The wishes of the board to have this condition remedied were conveyed to the Board of Commissioners of the District of Columbia, and I have to report that they have acted favorably, and that the sidewalk immediately north of the new building is now free from hucksters, who have been moved over to the north side of B street in front of the vacant lot known as "Haymarket Square."

DARWIN CELEBRATION.

The secretary said: "By resolution of the board I attended the ceremonies in commemoration of the centenary of Charles Darwin's birth, which were held at the University of Cambridge from June 22 to 24, when I presented the Institution's greetings in a formal address. I was honored by having conferred upon me the title of doctor of science."

CHANGE OF DATE FOR ANNUAL MEETING.

The secretary brought up the matter of a suitable date for the annual meeting, stating that difficulty was experienced in selecting a day of the week that would be most convenient for all the members of the board.

After discussion Senator Cullom offered the following resolution, which was adopted:

Resolved, That hereafter the Board of Regents of the Smithsonian Institution shall hold their annual meeting on the second Thursday in December and a supplementary meeting on the second Thursday in February.

THE SECRETARY'S STATEMENT.

Progress on the new building for the National Museum.—The failure on the part of several contractors to properly fulfill their agreements has not only greatly delayed the completion of the building, but has so increased the cost of construction that it has been necessary to proceed with extreme caution in the effort to keep within the limits of the appropriation.

The entire exterior of the building has been finished, except the laying of the main approaches, for which, however, the granite has been cut and delivered. Of the interior practically all the halls and

ranges for the exhibition and storage of collections and for the laboratories and workshops are now in use. The moving of the collections was begun last summer, and the occupation of the ground floor and third story should be completed by the end of the winter. The fitting up of the two great exhibition floors will require a much greater length of time, but it is expected that some parts of the exhibition collections can be made accessible to the public before the year is ended.

The heating and electrical plant already installed has developed sufficient capacity to also meet the requirements of the two older buildings. The economy thus effected will be very appreciable. Congress failed to supply means for adapting the upper hall of the Smithsonian building to the purposes of the National Gallery of Art, and a portion of one of the skylighted halls in the new building will be temporarily assigned to the paintings.

Art collection.—After discussion Senator Lodge offered the following resolutions, which were adopted:

Resolved, That the Board of Regents of the Smithsonian Institution hereby authorize the Secretary of the Institution to issue in their name invitations for a private view of the paintings of the National Gallery of Art upon the completion of their temporary installation in the new building for the National Museum.

Resolved, further, That the expenses connected with this reception be charged against the funds of the Institution.

Mount Whitney and Mount Wilson operations.—Under an allotment from the Hodgkins fund for the building of a stone and steel hut or shelter on Mount Whitney, California, at an elevation of 14,502 feet, the structure has been completed for the use of scientific observers who desire to avail themselves of the unusually favorable atmospheric conditions on that summit. On September 3 Mr. Abbot, director of the Smithsonian Astrophysical Observatory, made successful observations there for the determination of the solar constant of radiation. A small cottage has also been erected on Mount Wilson, close to the Smithsonian observatory shelter on that mountain, to be used as quarters for the observers.

Inauguration of president of Harvard University.—In connection with the inauguration of Dr. Abbott Lawrence Lowell as president of Harvard University on October 6 I visited Cambridge as the representative of the Smithsonian Institution and presented its formal greetings.

International Congress on Hygiene and Demography.—The secretary stated that the International Congress on Hygiene and Demography would be held in Washington from September 26 to October 1, 1910, and he had received a communication from the secretary-general of the congress, Dr. John S. Fulton, stating that a committee of three had

been appointed for the purpose of arranging for the housing of the congress, of which committee the Secretary of the Smithsonian Institution had been designated chairman.

This brought up the question of a suitable building for such purposes. There was no place now convenient, and it had become necessary, if the United States Government were to continue inviting foreign bodies to hold their conventions in Washington, that provision be made for their reception in suitable quarters of a permanent character. In accordance with the policy announced in the secretary's report of June 30, 1907, the Smithsonian Institution was doing what it could to help in this manner.

Senator Cullom remarked that if the Government were not willing to provide suitable accommodations for its guests it ought not to invite them.

Representative Mann agreed with this view and said that the Government was saved from disgrace at the time of the tuberculosis congress only by the fact that the new building for the National Museum was sufficiently far advanced in construction to permit its use for meetings and exhibits. He asked if the Government should provide for the erection of such a building as was being discussed and placed it under the control of the Smithsonian Institution, would it be possible to prevent it from being used permanently by the various organizations.

The secretary replied that that would depend entirely upon the policy of the Board of Regents; that if they decided against such permanent occupation the secretary would undoubtedly see that their wishes were regarded.

Death of Dr. Anton Dohrn.—For over sixteen years, as detailed in the annual reports of the secretary to the board, the Institution has supported a table at the Naples Zoological Station for the use of American biologists. The founder and director of the station, Dr. Anton Dohrn, has extended many courtesies to the Institution in this connection and has always shown entire sympanthy with the wishes of the Institution in arranging for the convenience of its appointees.

It has seemed fitting, therefore, to announce to the board the death of this gentleman, which occurred on September 29 last. At the request of the Institution the Department of State designated the American consul at Naples to represent the Institution officially at the funeral.

I have already communicated the Institution's sympathy to the son of Doctor Dohrn, and have received from him a letter announcing his appointment to succeed his father and his hope to continue the relations which have existed between the Institution and the station for so many years.

SMITHSONIAN AFRICAN EXPEDITION.

The secretary said that he was glad to report that the Smithsonian African expedition in charge of Colonel Roosevelt was proceeding on the plan originally adopted, and that it would continue until the expedition reached Khartoum, probably about May, 1910. He said that funds had been secured from 25 subscribers to the amount of $40,500 and that he expected to obtain about $10,000 more.

The total number of skins of large and small mammals and birds taken up to December 10, was 6,663. In addition, there were many skulls and skeletons, and about 2,500 sheets of plants.

Up to the present time four shipments of specimens had been received from the expedition, numbering over 3,000. The material yet to come comprised rather more than half of the collections made to date and included about 6 elephants, 2 Somali giraffes, a complete group of ostriches (young and eggs, as well as adults), and also many antelopes and other animals not previously taken.

Live animals for the National Zoological Park.—As a result of the expedition, Mr. W. N. McMillan, of Juja farm, near Nairobi, had presented the National Zoological Park with a collection of living lions and other African animals. A representative of the park was sent to Nairobi to receive this gift, and to arrange for the transfer and care of these valuable animals.

RESEARCH FUNDS FOR THE INSTITUTION.

The secretary stated that he was making earnest efforts to increase the research funds of the Institution; that there were various lines of work which the Government would hardly feel justified in taking up, but which would come within the scope of the Institution's activities, and which it would assume, provided funds could be had for them.

REGULAR MEETING, FEBRUARY 10, 1910.

Present: Hon. Melville W. Fuller, Chief Justice of the United States (chancellor), in the chair; Hon. James S. Sherman, Vice-President of the United States; Senator Shelby M. Cullom; Senator Henry Cabot Lodge; Senator Augustus O. Bacon; Representative James R. Mann; Representative William M. Howard; Hon. George Gray; Hon. John B. Henderson; Dr. Alexander Graham Bell, and the secretary, Mr. Charles D. Walcott.

REAPPOINTMENT OF REGENTS.

The chancellor announced that on December 14, 1909, the Speaker of the House of Representatives had reappointed Representatives John Dalzell, James R. Mann, and William M. Howard as Regents.

He also stated that Hon. John B. Henderson and Dr. Alexander Graham Bell had been reappointed Regents by joint resolution of Congress.

LANGLEY MEMORIAL TABLET.

The secretary, on behalf of the committee on a memorial tablet to commemorate the work of Samuel Pierpont Langley in connection with aeronautical science, reported that the committee recommends that there be modeled in low relief a tablet along the lines of Saint-Gauden's work, cast in bronze, in general rectangular shape, to contain a bas relief of the bust of Mr. Langley, and that the last model of the Langley aerodrome, in full flight, be suggested in the background; the tablet to bear the lettering:

SAMUEL PIERPONT LANGLEY
1834–1906

SECRETARY OF THE SMITHSONIAN INSTITUTION
1887–1906

and to bear also the text of what is known as Langley's Law as to relation of speed to power in aerial motion, as follows:

These new experiments (and theory also when viewed in their light) show that if in such aerial motion, there be given a plane of fixed size and weight, inclined at such an angle, and moved forward at such a speed, that it shall be sustained in horizontal flight, then the more rapid the motion is, the less will be the power required to support and advance it.

The committee further recommends that the tablet be placed in the vestibule of the Smithsonian Institution, at the left of the entrance.

A suggestion was made that the tablet also carry the date of the first successful flight of the Langley model. After discussion, Judge Gray offered the following resolution which was adopted:

Resolved, That the report of the committee be accepted; that the committee be increased by the addition of Dr. Alexander Graham Bell, and that the report be referred back to the committee with power to act, with the request that the tablet contain an inscription showing the date of the first flight of the Langley aerodrome model.

SMITHSONIAN AFRICAN EXPEDITION.

The secretary read the following letter:

NAIROBI, *December 15, 1909.*

To the SECRETARY OF THE SMITHSONIAN INSTITUTION.

SIR: I have to report that the Smithsonian expedition under my charge has now finished its work in British East Africa and is about to leave for Uganda. The collections made in British East Africa include:

Mammals, large, in salt	550
Mammals, small	3,379
Birds	2,784
Reptiles and batrachians, about	1,500
Fresh-water and marine fish, about	250
Total vertebrates	8,463

In addition the collections include a large number of mollusks and other invertebrates, several thousand plants; in the neighborhood of two thousand photos; anthropological materials, etc.

Very respectfully, THEODORE ROOSEVELT.

The secretary stated further that the Associated Press dispatches indicate that the expedition had secured five specimens of the white rhinoceros, a very rare animal. This had been accomplished through the concession of the King of Uganda who had given permission for the party to hunt in his domain. The collections included many duplicates which would be useful for comparative study.

SECRETARY'S STATEMENT.

National Museum.—The secretary stated that it was hoped to open a portion of the new building to the public by March 1, but that the opening of the entire building would probably not take place until the close of the year. The question of opening the Museum at night and on Sundays was discussed, and after a full interchange of views, the Vice-President offered the following resolution, which was adopted:

Resolved, That the secretary be authorized and directed to prepare proper regulations for the opening, on Sundays, for a period not longer than five hours, of such portions of the National Museum as he may deem expedient, provided that the appropriations for the maintenance of the Museum will permit.

George Washington memorial building.—The secretary spoke of the proposed movement of the George Washington Memorial Association to erect in Washington a memorial building, which would be used as a center for the scientific, literary, and other educational associations. He mentioned the meeting to be held in this connection at the Hall of the Daughters of the American Revolution on February 19, and said that among the speakers would be President Taft, Senator Lodge, and Senator Burton.

The secretary said that his purpose in bringing the matter before the board was merely to show that there was a prospect of securing such a building as would afford a much needed relief to the present crowded condition of the Smithsonian building, brought about in part by the accommodations which the Institution had offered to the National Academy of Sciences, the American Association for the Advancement of Science, the American Historical Association, and others.

The secretary added that there was great need of a building of the kind referred to; for instance, at the International Congress on Hygiene and Demography there would be 3,000 persons, and it would be necessary to scatter them through possibly eight or ten buildings. In answer to an inquiry, he said that the George Washington memorial building would be erected by popular subscription, and that it would be entirely independent of the George Washington University.

Death of Ferdinand V. Berry.—The secretary announced with regret the death, on January 27, 1910, of Mr. Ferdinand V. Berry, chief clerk of the International Exchanges of the Institution. Mr. Berry entered the service of the Institution in January, 1884, as a clerk, and was advanced from grade to grade to the position he held at the time of his death. He was a capable and valuable employee.

Oldroyd collection.—The secretary said that at various times bills had been introduced in Congress providing for the purchase of what was known as "The Oldroyd collection of Lincoln relics," now located in the building No. 516 Tenth street, NW., the house in which Lincoln died; his object in bringing the matter before the board was to call attention to the proposal to organize what might be described as a "National" museum for this collection; he thought that the establishment of such independent "National" museums should be discouraged by the board which had under its charge the legal National Museum; he was not asking for any definite action as he thought that his object could very well be accomplished if he could enlist the interest of the congressional Regents when matters of this kind were brought before Congress.

Andrews will case.—Senator Henderson said that he had requested Mr. Frank W. Hackett to make a personal statement to the board in relation to the present condition of the Andrews will case, particularly with regard to a proposed action for testing the validity of the Andrews bequest in Ohio.

Mr. Hackett submitted his statement, and, after discussion, the Vice-President offered the following resolution, which was adopted:

Resolved, That in view of the statement made by Mr. Frank W. Hackett to the Board of Regents, the entire matter of the Andrews will case be referred back to the executive committee with full power to act.

PRESENTATION OF LANGLEY MEDAL TO MESSRS. WILBUR AND ORVILLE WRIGHT.

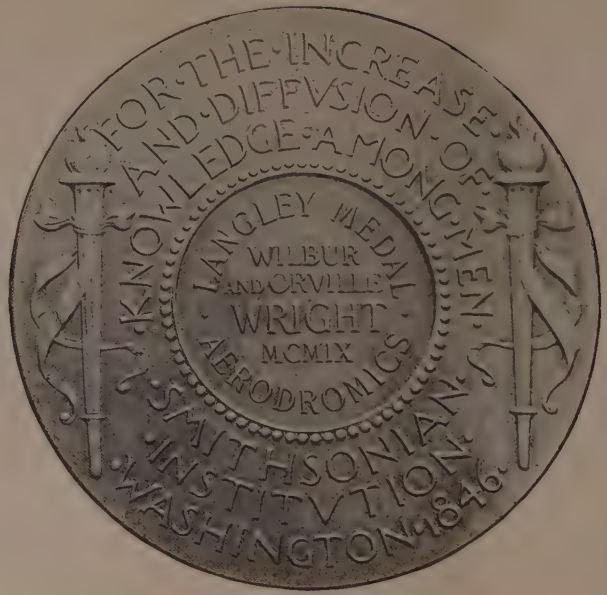
The chancellor said that the next business before the meeting was the presentation of the Langley medals to the Wright brothers. Accordingly, these gentlemen were escorted to the Regents room and introduced to the board.

HISTORICAL ADDRESS BY DR. ALEXANDER GRAHAM BELL.

Doctor Bell said:

Mr. Chancellor, the award of the Langley medal to the Brothers Wilbur and Orville Wright emphasizes the fact that we are living in an age of great achievements.

The twentieth century had hardly dawned when the world was startled by the discovery of radium, which has opened up an entirely



THE LANGLEY MEDAL.

new field to science, and which has led us to modify profoundly our conceptions regarding the constitution of matter.

Another new field has been revealed to us through the development of wireless telegraphy and telephony; and we now utilize the vibrations of the etherial medium of space for the transmission of thought.

Then again we may note the most revolutionary changes going on before our eyes relating to methods of transportation.

The appearance of the hydroplane boat probably foreshadows a revolution in marine architecture and propulsion. On land we see motor cycles, automobiles, and electric cars displacing the horse. Petroleum and electricity have become powerful rivals of steam, and we seem to be on the eve of a revolution in our methods of railroad transportation, through the application of the gyroscope to a monorail system. And now aerial transport has come, dispensing with rails and roads altogether. The air itself has become a highway, and dirigible balloons and flying machines are now realities.

How well the predictions of Langley have been fulfilled. We now recognize that he was right when he said a few years ago (1897) that—

> The world indeed will be supine if it does not realize that a new possibility has come to it and that the great universal highway overhead is now soon to be opened.

It has been opened, and who can foretell the consequences to man?

One thing is certain: That the physical obstacles to travel have been overcome, and that there is no place on the surface of the globe that is inaccessible to civilized man, through the air.

Does this not point to the spread of civilization all over the world and the bringing of light to the dark continents of the earth?

THE PIONEERS OF AERIAL FLIGHT.

Who are responsible for the great developments in aerodromics of the last few years? Not simply the men of the present, but also the men of the past.

To one man especially is honor due: Our own Dr. S. P. Langley, late Secretary of the Smithsonian Institution. When we trace backward the course of history we come unfailingly to him as the great pioneer of aerial flight.

We have honored his name by the establishment of the Langley medal; and it may not be out of place on this, the first occasion for the presentation of the medal, to say a few words concerning Langley's work.

LANGLEY'S WORK.

Langley devoted his attention to aerodromics at a time when the idea of a flying machine was a subject for ridicule and scorn. It was as much as a man's reputation was worth to be known to be at work upon the subject. He bravely faced the issue, and gave to the world his celebrated memoir entitled "Experiments in Aerodynamics."

In this work he laid the foundations for a science and art of aerodromics, and raised the whole subject of aerial flight to a scientific plane.

The knowledge that this eminent man of science believed in the practicability of human flight gave a great stimulus to the activities of others and started the modern movement in favor of aviation that is such a marked feature of to-day.

Everyone now recognizes the influence exerted by Langley on the development of this art. The Wright brothers, too, have laid their tribute at his feet.

"The knowledge," they say, "that the head of the most prominent scientific institution of America believed in the possibility of human flight was one of the influences that led us to undertake the preliminary investigations that preceded our active work. He recommended to us the books which enabled us to form sane ideas at the outset. It was a helping hand at a critical time, and we shall always be grateful."

CONTRIBUTIONS TO THE SCIENCE OF AERODROMICS.

Langley's experiments in aerodynamics gave to physicists, perhaps for the first time, firm ground on which to stand as to the long disputed questions of air resistances and reactions. Chanute says:

(*a*) They established a more reliable coefficient for rectangular pressures than that of Smeaton.

(*b*) They proved that upon inclined planes the air pressures were really normal to the surface.

(*c*) They disproved the "Newtonian law" that the normal pressure varied as the square of the angle of incidence on inclined planes.

(*d*) They showed that the empirical formula of Duchemin, proposed in 1836 and ignored for fifty years, was approximately correct.

(*e*) That the position of the center of pressure varied with the angle of inclination, and that on planes its movements approximately followed the law formulated by Jöessel.

(*f*) That oblong planes, presented with their longest dimension to the line of motion, were more effective for support than when presented with their narrower side.

(*g*) That planes might be superposed without loss of supporting power if spaced apart certain distances which varied with the speed.

(*h*) That thin planes consumed less power for support at high speeds than at low speeds.

The paradoxical result obtained by Langley that it takes less power to support a plane at high speed than at low, opens up enormous possibilities for the aerodrome of the future. It results, as Chanute has pointed out, from the fact that the higher the speed, the less need be the angle of inclination to sustain a given weight, and the less therefore the horizontal component of the air pressure.

It is true only, however, of the plane itself, and not of the struts and framework that go to make up the rest of a flying machine. In

order, therefore, to take full advantage of Langley's law, those portions of the machine that offer head resistance alone without contributing anything to the support of the machine in the air, should be reduced to a minimum.

CONTRIBUTIONS TO THE ART OF AERODROMICS.

After laying the foundations of a science of aerodromics, Langley proceeded to reduce his theories to practice.

Between 1891 and 1895 he built four aerodrome models—one driven by carbonic acid gas, and three by steam engines.

On the 6th of May, 1896, his *Aerodrome No. 5* was tried upon the Potomac River near Quantico. I was myself a witness of this celebrated experiment, and secured photographs of the machine in the air, which have been widely published.[a]

This aerodrome carried a steam engine and had a spread of wing of from 12 to 14 feet. It was shot into the air from the top of a house boat anchored in a quiet bay near Quantico.

It made a beautiful flight of about 3,000 feet, considerably over half a mile. It was indeed a most inspiring spectacle to see a steam engine in the air flying with wings like a bird. The equilibrium seemed to be perfect, although no man was on board to control and guide the machine.

I witnessed two flights of this aerodrome on the same day and came to the conclusion that the possibility of aerial flight by heavier-than-air machines had been fully demonstrated. The world took the same view and the progress of practical aerodromics was immensely stimulated by the experiments.

Langley afterwards constructed a number of other aerodrome models which were flown with equal success, and he then felt that he had brought his researches to a conclusion, and desired to leave to others the task of bringing the experiments to the man-carrying stage.

Later, however, encouraged by the appreciation of the War Department, which recognized in the Langley aerodrome a possible new engine of war, and stimulated by an allotment of $50,000 from the Department, he constructed a full-sized aerodrome to carry a man.

Two attempts were made, with Mr. Charles M. Manly on board as aviator, to shoot the machine into the air from the top of a house boat, but on each occasion the machine caught on the launching ways and was precipitated into the water.

The public, not knowing the nature of the defect which prevented the aerodrome from taking the air, received the impression that the machine itself was a failure and could not fly.

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[a] A photograph of this flight was here shown.

This conclusion was not warranted by the facts; and to me and to others who have examined the apparatus, it seems to be a perfectly good flying machine—excellently constructed and the fruit of years of labor. It was simply never launched into the air, and so has never had the opportunity of showing what it could do. Who can say what a third trial might have demonstrated? The general ridicule, however, with which the first two failures were received prevented any further allotment of money to give it another trial.

CONCLUSION.

Langley never recovered from his disappointment. He was humiliated by the ridicule with which his efforts had been received, and had, shortly afterwards, a stroke of paralysis. Within a few months a second stroke came and deprived him of life.

He had some consolation, however, at the end. Upon his deathbed he received the resolution of the newly formed "Aero Club of America," conveying the sympathy of the members and their high appreciation of his work.

Langley's faith never wavered, but he never saw a man-carrying aerodrome in the air.

His greatest achievements in practical aerodromics consisted in the successful construction of power-driven models which actually flew. With their construction he thought that he had finished his work; and, in 1901, in announcing the supposed conclusion of his labors he said:

> I have brought to a close the portion of the work which seemed to be specially mine—the demonstration of the practicability of mechanical flight—and for the next stage, which is the commercial and practical development of the idea, it is probable that the world may look to others.

He was right, and the others have appeared. The aerodrome has reached the commercial and practical stage; and chief among those who are developing this field are the brothers Wilbur and Orville Wright. They are eminently deserving of the highest honor from us for their great achievements.

I wish to express my admiration for their work and believe that they have justly merited the award of the Langley medal by their magnificent demonstrations of mechanical flight.

PRESENTATION ADDRESS BY SENATOR HENRY CABOT LODGE.

Senator Lodge said:

Mr. Chancellor, founded for the increase and diffusion of knowledge among men, the Smithsonian Institution has always considered that one way in which it could most appropriately fulfill the purposes of its founder was by the recognition of great achievements in science.

Identified with the science of aerodromics through the work of its eminent secretary, Doctor Langley, it has had a peculiar interest in what has been done in that field.

We have just heard of the results achieved by Professor Langley, and I think it is not too much to say that his life in a measure was sacrificed to the work which he did in the establishment of the scientific principles of aerial flight, to which he gave so much of his life work and for which recognition is now given throughout the entire world. Nothing, therefore, could have given Mr. Langley more pleasure than to recognize the men who have successfully demonstrated the soundness of his principles by their application to actual flight in machines heavier than the air. I repeat that nothing could be more appropriate than that such a demonstration should receive the recognition of the Smithsonian Institution. We are glad to do this in the case of the Wright brothers, not only on account of their courage, their energy, and the ability they have shown, but also because we feel, I think I may say, a not unreasonable pride in the fact that they are Americans. It is peculiarly characteristic of Americans to be pioneers; pioneers across the great continent on which we live; pioneers by sea, and now pioneers by air; and to Wilbur and Orville Wright, pioneers of what Doctor Langley calls "the great universal highway overhead," who by their achievements have added honor to the American name and nation, we now present the first Langley medal that the Institution has conferred.

REMARKS BY WILBUR WRIGHT.

The chancellor then presented the medals to Messrs. Wilbur and Orville Wright, saying that it gave him particular pleasure to do so.

Mr. Wilbur Wright addressed the board as follows:

Mr. Chancellor, at different times my brother and myself have received recognition for the work which we have attempted to do in the line of aerial research, but in no instance has such recognition given us greater pleasure than that which we now receive from the Smithsonian Institution. This is particularly the case because the Institution, through the studies and work of Professor Langley, has always taken especial interest in scientific research in matters relating to the physical properties of the air, and this interest has extended to practical attempts to fly. We are very much gratified, therefore, that the Institution has thought our work worthy of this honor, for which we desire to express our sincere thanks. A subject of research which has not yet been completed, and one to which Doctor Bell has called attention in the work of Professor Langley, is the coefficient of air pressure; that is, the pressure of wind at a certain speed on a plane of a certain size. A great many investigations have been made by

Professor Langley, and other people have also experimented in this art, but for the most part the results have not yet been brought into shape to be presented to the public. Our own work in this particular investigation we have been obliged to set aside for a while on account of the press of business matters, but it is our intention, as soon as these business details are arranged, to take it up again and present the results to the world. There is a great deal of work to do in this line, and a great many other researches to be taken up, which will keep a large number of investigators busy for a lifetime, and I venture to express the hope that the Smithsonian Institution will continue to encourage the labors of those engaged in these fields.

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1910

ADVERTISEMENT.

The object of the General Appendix to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution, from a very early date, to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and this purpose has, during the greater part of its history, been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880 the secretary, induced in part by the discontinuance of an annual summary of progress which for 30 years previous had been issued by well-known private publishing firms, had prepared by competent collaborators a series of abstracts, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1910.

MELVILLE WESTON FULLER. 1833-1910.

Chancellor of Smithsonian Institution, 1889-1910.

MELVILLE WESTON FULLER—1833–1910.

[With 1 plate.]

By Charles D. Walcott,

Secretary of the Smithsonian Institution.

Melville Weston Fuller, doctor of laws, Chief Justice of the United States, chancellor of the Smithsonian Institution, was born at Augusta, Me., February 11, 1833, and died at his summer home, Sorrento, Me., on the morning of July 4, 1910. He became a statutory member of the establishment of the Smithsonian Institution, and also a member of the Board of Regents on October 8, 1888, by virtue of his appointment as the Chief Justice of the United States. He was elected chancellor of the Institution by the Board of Regents at its annual meeting January 9, 1889.

The chancellors who preceded Chief Justice Fuller were: Vice President George Mifflin Dallas, 1846–1849; Vice President Millard Fillmore, 1849–1850; Chief Justice Roger Brooke Taney, 1850–1864; Chief Justice Samuel Portland Chase, 1864–1873; and Chief Justice Morrison Remick Waite, 1874–1888.

For 22 years, until his death in 1910, Chief Justice Fuller was most deeply interested in the general welfare of the Institution. He presided over the meetings of the Board of Regents most wisely and judiciously. With one exception, there was not a meeting of the regents during that entire period when he failed to be present.

The Regents of the Institution expressed their sorrow in the following words of tribute to his memory, adopted at the annual meeting of the board on December 8, 1910:

Whereas the Board of Regents of the Smithsonian Institution have received the sad intelligence of the death, on July 4, 1910, of Melville Weston Fuller, Chief Justice of the United States, and for twenty-two years chancellor of the Institution; therefore be it

Resolved, That we desire here to record our profound sorrow at the severing of the tie that has bound us to him for so long a period of honored service; that we feel keenly the loss of a wise presiding officer,

whose vast store of learning and gracious dignity have proved so invaluable in the deliberations of this board, and whose loyal interest in the Smithsonian Institution has been a source of inspiration to his colleagues.

Resolved, That we share in the grief of the nation at the passing away of one who was at once a distinguished leader of the greatest legal tribunal of our land, an eminent jurist, a patriotic citizen, a shining example of Christian gentleness, and who also possessed so charming a personality as a man and as a friend.

Resolved, That we respectfully tender to the members of the family of our late associate, our sincerest sympathy in their great bereavement.

Resolved, That an engrossed copy of these resolutions be transmitted to the family of the late chancellor.

An adequate review of the life of that eminent jurist would require more space than can be devoted to the subject in the present report of the board to Congress. Numerous eulogies in his memory have been delivered by members of the bar of the Supreme Court and by jurists throughout the land. It is fitting that selections from some of these tributes should here be recorded:

At a meeting of the bar of the Supreme Court and of its officers on December 10, 1910, Mr. Richard Olney, chairman of the meeting, and formerly an associate of Chief Justice Fuller on the Board of Regents of the Smithsonian Institution said:[1]

"Gentlemen of the bar: The death of the Chief Justice of the United States is an event of the first importance. Undoubtedly it does not impress the general public as does the demise of a President in office. It does not elicit the same manifestations of general sorrow, it is not marked by the same profusion of funeral pageantry and funeral oratory. It is nevertheless an occurrence of much greater moment by reason both of the longer tenure of the Chief Justice's office and of the unique character of its functions. No single Presidency, probably no number of Presidencies combined, has ever influenced the destinies of this country so vitally and so largely as did the single Chief Justiceship of John Marshall. In adding Melville W. Fuller to the roll of the country's Chief Justices, therefore, one of our great Presidents exercised his highest prerogative and performed the act of his official life most far-reaching and enduring in its consequences. That President Cleveland's choice was fortunate has long been generally conceded. It put at the head of the national judiciary a well-educated scholar and a well-trained lawyer; a man who had won distinction at the bar on his merits and by his own efforts; who was not the lawyer of but one client or in but one field, but was expert in all varieties of professional work; who,

[1] The extracts herein are from "Proceedings of the bar and officers of the Supreme Court of the United States in memory of Melville Weston Fuller, December 10, 1910." Washington: 1911, pp. 1–108.

starting in the extreme northeastern corner of the Union where he indulged himself in such various activities as being president of the city council, city solicitor, and newspaper editor, soon took Horace Greeley's advice to young men, and three years after his admission to the bar established himself in the metropolis of the West; who from the beginning and as long as he remained at the bar took the good citizen's interest in politics, and thus put himself in touch with the currents of popular thought and sentiment; and who from the outset of his career was in thorough sympathy with the democratic principles which underlie our political institutions. Once inducted into his great office, he from the beginning acquitted himself so judiciously and ably and yet so modestly as both to increase the esteem of friends and to forestall the cavils of would-be critics. The limits of this occasion do not permit any adequate analysis of his merits as a judge or any satisfactory estimate of those labors on the Supreme Bench which occupied nearly 23 years of his life and are only partially shown in over 90 volumes of United States Supreme Court Reports. It is, however, only just and proper to say that, large and novel and momentous in their aspects and consequences as are many of the legal issues constantly presented to the Supreme Court of the United States, Chief Justice Fuller never failed to rise to the height of the occasion, and, whether as one of a minority or a majority of the court, to worthily deal with them. Many of his opinions are models of lucid statement, of exhaustive research, of close and conclusive reasoning. * * *

"Besides doing his share of the legal work of the Supreme Court, the Chief Justice is its executive and presiding officer. His qualities in both capacities have always received unstinted commendation. He was anxious to keep the docket moving, to prevent any congestion of the business of the court, and to avoid all delays in the disposition of causes not absolutely essential to the due administration of justice. That he accomplished those purposes with great success was due largely to his native tact and his invariable good temper. Over the public deliberations of the court he presided with a dignity and grace all his own. He was a patient and attentive listener and was content that counsel should have full opportunity to develop his case in his own way without interruption. He was specially considerate of the debutant, whether young or old, and many a first appearance at the bar of the court at Washington has been saved from wreck by the encouraging nod and smile of the Chief Justice. For those of us to whom the zest of life is largely in memories, few things can be more gratefully recalled than the spectacle of the Chief Justice sitting with his colleagues to listen to the opening of some newcomer, and by every word and tone and gesture expressing

the assurance that, whether his case or his presentation of it was good, bad, or indifferent, he had a well-wisher at the head of the court. It must not be understood that these occasions elicited anything unusual or exceptional in the bearing of the Chief Justice. On the contrary, the same considerate and gracious demeanor marked his entire administration of his duties as chief of his court. No one was snubbed, no one left the court with a right to feel that for some occult reason he was not persona grata. During his Chief Justiceship the court at Washington has been universally acclaimed as the most agreeable tribunal in the country to appear before. Members of the bar found there a forum in which the height of dignity was combined with the height of simplicity, in which ceremony did not degenerate into fussiness, and in which form was not exalted over substance. All can not fail to miss the central figure, in whom perfect kindliness of manner was joined to equal inflexibility in all essentials. They who knew him more intimately, and as the man as well as the magistrate, can not but grieve for the passing of a friend and comrade whose unique and personal charm mere words are inadequate to express. Fortunate in his life and in the opportunities of a great career clearly apprehended and worthily utilized, the Chief Justice was also fortunate in the circumstances of his death, which found him still in harness and still charged with the responsibilities of his great office. 'When,' says Lord Bacon, 'a man hath obtained worthy ends and expectations, the sweetest canticle is "*Nunc Dimittis*."'"

At the meeting referred to above the following resolutions were adopted:

Resolved, That the members of the bar of the Supreme Court desire to express their profound regret at the death of Melville Weston Fuller, eighth Chief Justice of the United States, and to record their high appreciation of his life and character and of his conspicuous and faithful service to his country.

Born in the State of Maine, he went to Chicago at the age of 23, when that great city was in its infancy, and there entered upon his long and distinguished professional career, which culminated in his elevation to the most exalted judicial station in our Government.

He secured the advantages of an academic and classical education at Bowdoin College, and always retained the habits and tastes of the student and scholar.

He was a man of the most extensive and varied reading in the profession, in governmental and political discussion and in general literature.

He rapidly achieved a commanding position at the then exceptionally brilliant bar of the city of his adoption, and for 32 years carried on an extended and diversified practice in the courts of his State; nor did he infrequently appear before the great tribunal over which he afterwards, and for 22 years, presided with such marked ability and distinction.

He was a man of singular beauty and purity of character.

While he was at the bar no one harbored a suspicion that the exigency of forensic controversy, in which he was almost constantly engaged, could ever tempt him to aught that was unfair or unworthy of the highest ideals of a noble and honorable profession.

As Chief Justice, it is enough to say that with conspicuous fidelity he fully and consistently maintained the best traditions of that high office. He took a deep interest in the efforts to secure peace between nations by international arbitration, and was appointed by our Government to membership in the permanent court established in 1899 by the first peace conference, and served in that capacity.

His character was marked by a gentle courtesy and consideration which constantly illuminated and attended upon the discharge of his important public duties, always marked his relations with the bar, and earned that popular confidence which goes out to him whom the people believe to be a merciful and considerate, as well as a just and impartial judge.

All this he was; and, endowed by nature with talents not inferior to those of his predecessors, possessed of attainments, training, and experience adequate to the exacting requirements of his great office, he filled it at all times in such a manner as to command the admiration and respect of the bar and the grateful appreciation of his countrymen.

On the morning of July 4 last, at his beautiful summer home, on the soil of the State in which he was born, and to which he remained always deeply attached, his long, useful, and honorable life ended; and when the sad announcement was made, we who had practiced in the great tribunal where he so long presided felt a deep sense of personal loss and personal bereavement that he had gone from us forever.

Resolved, also, That the Attorney General be asked to present these resolutions to the court and to request that they be inscribed upon its permanent records.

And that the chairman of this meeting be requested to transmit a copy of the resolutions to the family of the late Chief Justice and an expression of our sincere sympathy with them in the great and irreparable loss which they have sustained.

In seconding the resolutions Mr. Lee S. Overman said:

"The people of this country, Mr. Chairman, have the greatest respect for the law for its own sake, and there is no country in the world which honors and respects its great expounders and administrators more than does ours; and the reputation of a great and upright judge is one of the greatest inheritances of a free and happy people. Our country has been blessed with a Supreme Court whose able, just, and upright justices have added to her history a crown of glory and been to the Republic and its people a shield of protection.

"With untiring labor, with a broad grasp of the principles which underlie the structure of our Government, in the light of their genius they have traced back the principles of the law to their fountain springs, and then, running them forward to their logical conclusion, with their expansiveness and flexibility, they have so applied them to

the great problems arising continually under new conditions incident to our progress and higher civilization that our republican institutions and the affairs of the people have not suffered.

"Chief Justice Fuller was among the greatest of these great and illustrious lawyers and judges, and it is therefore most fitting that we should do honor to his memory and hold these appropriate exercises. By so doing we not only honor him, but we foster that spirit which always exists among a free people, and which tends to conserve our highest ideals and uphold our free institutions. Great men make great history, and love, veneration, and respect for them make a great people.

"The great Italian poet, speaking of the mighty presence which he met in that mystic realm of departed spirits, paid a great tribute to him when he said, 'His was a life so round and full that when it rolled out of time into eternity the world knew not how great a void was left until a generation has passed away.' This thought is applicable to him whom we meet to honor to-day.

"He was not a young man, dying in the fullness of his strength and power with unfilled possibilities. This is no place for sorrow. This man died after a full, well-rounded, completed life. He died when age was ripe, with the harness of his great official position yet upon him, and after maintaining the best traditions of his great office and of a great lawyer. Crowned with honor, ripe with age, respected by a great people, he leaned his white head beneath the soft touch of death—a death befitting such a life.

> "'Why weep ye, then, for him, who, having run
> The bounds of man's appointed years, at last,
> Life's blessings all enjoyed, life's labor done,
> Serenely to his final rest has passed?'"

Mr. Charles E. Littlefield, on the same occasion, said:

"* * * He came from a family of able preachers and lawyers. With Mr. Chief Justice Shaw, of Massachusetts, one of the greatest justices that ever sat on the Massachusetts bench, he had a common ancestor in Rev. Habijah Weld, called in his time 'a perfect Boanerges in the pulpit.' Rev. Habijah Weld was the fourth in a succession of four generations of preachers. Mr. Fuller's paternal and maternal grandfathers were both lawyers of note. Hon. Nathan Weston, his mother's father, was one of the first associate justices of the Maine supreme court and its chief justice for seven years, and a lawyer and judge of unusual ability. His father and mother each had a brother who was a lawyer. He graduated from Bowdoin College when 20 years of age, destined to become one of the most distinguished of an alumni which has a larger percentage of men of eminence and note than that of any other educational institution in the country. He had by inheritance an aptitude for the law. Ad-

mitted to the bar in Maine, desiring a wider field, in 1856 he went to Chicago, where, with gratifying success, he practiced his profession, attaining a high rank, until his appointment as Chief Justice of the Supreme Court of the United States, April 30, 1888. His practice was general, varied, and extensive, involving much important litigation. With great abilities, a ripe classical scholar, learned and profound in the law, diligent, industrious, conscientious, courageous, and patriotic, of the highest personal character, he brought to the discharge of the duties of the great office the abilities, qualities, and characteristics that enabled him to achieve his signal success. The dignity, urbanity, kindness, consideration, and gentle courtesy with which he presided over the deliberations of the Supreme Court of the United States endeared him not only to his associates on the bench but won for him the love and respect of a great profession. Of him it could be truthfully said, 'And they shall judge the people with just judgment. * * *'"

Mr. George E. Price said:

* * * "No other court in the world is intrusted with such powers as this court. It deals not only with great questions of controversy arising between individual citizens of different States and between citizens of foreign countries and our own people, but to it is intrusted the ultimate interpretation of the laws and Constitution of the United States, with power to declare null and void not only acts of the legislatures of the different States, so far as they come in conflict with the Federal Constitution, but also the acts of Congress, the highest lawmaking power of the Federal Government. In addition to these great powers, this court is also given jurisdiction to settle controversies between the sovereign States of this Union, and in the past it has been called upon to settle controversies which involved the very autonomy of the States concerned, the integrity of their territory and their governmental jurisdiction and power. It is the first great instance of what is in effect modern international arbitration. In the settlement of these controversies between the States this court has no statute law to govern it and seldom any provision of any written constitution, but it is obliged to invoke and apply the eternal principles of an elevated and perfect justice, unfettered by technical subtleties and petty forms, the same fundamental doctrines of international law, which by the common consent of mankind are the basis of the intercourse of the civilized world. To its great credit it can be said that in these controversies between the States its judgments have always been acquiesced in and respected and carried out without question.

"Such are the powers of this great court over which the late Chief Justice presided for nearly a quarter of a century. To-day we,

the members of the bar of this court, are assembled to pay tribute to his memory, and all of us here assembled, as well as other members of the bar of this court from all sections of the country, those who have taken part in the great contests before it on the one side or the other, those whose interests or the interests of whose clients have been affected by its judgments, with one accord declare and bear testimony that he discharged the great duties of his position with becoming dignity, uniform courtesy, with signal ability and unquestioned fidelity and integrity; discharged these duties in such manner as to reflect great credit not only upon himself but upon the court and the Nation at large. Speaking for myself and, in some measure, for the bar of the State of West Virginia, I am here to unite with the other members in paying this just tribute to the memory of the late Chief Justice; and, having said this, there seems to be nothing more to say. I know of no way to pay greater honor to the memory of any man.

"Chief Justice Fuller met the responsibilities arising out of the great questions presented to this court in his day, and this is all that can be said of his predecessors in this great office. Marshall exercised a great influence in deciding the questions that arose during the constructive period of our Government. They were far-reaching questions, and the influence of his decisions is felt in the administration of the Government to this day. Chief Justice Taney, his successor, was confronted with the burning questions that arose in the great controversies preceding and during our terrible Civil War. Chase and Waite dealt with the important questions which arose out of the war—the reconstruction period, requiring the readjustment of many things which had been considered settled; the readjustment of the relations between the two sections which had been at war with each other, and the interpretation of the amendments to the Constitution which grew out of the war. And Chief Justice Fuller has been obliged to grapple with the great questions arising out of the stupendous industrial development which has taken place in the last quarter of a century—questions of interstate commerce and transportation, questions of great trusts and combinations of capital, questions of the mutual rights of capital and labor, questions relating to the regulation of railroads, besides the perplexing questions arising out of the development of this Nation into a world power since the Spanish War, involving our relations to our colonies acquired by reason of that war. No one can say that these questions are of any less importance than those which arose in any former period of the Government. He and his associates on this bench have met and disposed of many of these questions as they have arisen in such manner as to command the respect of the whole country and

to escape serious criticism. This is just what Marshall, Taney, Chase, and Waite, and their associates did with the great questions of their days; and so Chief Justice Fuller will stand forth in history as a worthy successor of the great Chief Justices who preceded him.

"The labors of the judge are along lines that make for peace—for the security of life, liberty, and property. It is his work to settle, in a peaceable manner, controversies that would otherwise result in the triumph of fraud, violence, and oppression and lead to war. The judge is essentially a peacemaker, and when we reflect that Chief Justice Fuller devoted 22 years of his life to this work may we not with propriety apply to him the beautiful beatitude which fell from the lips of Him who is the Judge of all the earth, in His sermon on the mount: 'Blessed are the peacemakers, for they shall be called the children of God'?"

The Supreme Court, on January 9, 1911, adopted resolutions identical with those adopted by the bar of that court on December 10, 1910. On that occasion the Attorney General of the United States, Mr. Wickersham, in presenting the resolutions, reviewed the more important decisions of the court under Chief Justice Fuller, and in conclusion said:

" * * * The Talmud compares the study of the law to a huge heap of dust that is to be cleared away. 'The foolish man says, "It is impossible that I should be able to remove this immense heap. I will not attempt it." But the wise man says, "I will remove a little to-day, some more to-morrow, and more the day after, and thus in time I shall have removed it all."' It was in this spirit that Chief Justice Fuller toiled during the years that he presided over this court. Much of the work of all courts is of but transitory importance, save in so far as it keeps ever burning the sacred lamp of justice to lighten the footsteps of men. But the labors of this tribunal are essential to the preservation of the liberties of a free people. In the largest proportion of causes submitted to its judgment every decision becomes a page of history and may become a part of a rampart against anarchy. To this court men look for the maintenance of those rights which our forefathers wrung from a reluctant monarch at Runnymede 800 years ago, which are now embodied in the Constitution of the United States, and which are as essential to the protection of the citizen against the tyranny of a hydra-headed tyrant of the future as they were against the monarchs of the past.

"The labors of the eighth Chief Justice are over, and his work in this court is submitted to the judgment of men. As he said of Justice Brewer, 'he died suddenly, but not the unprepared death from which we pray to be delivered,' and having finished his course in faith he doth now rest from his labors."

Chief Justice White, in responding to the words of the Attorney General, said:

"Mr. Attorney General: The resolutions which you present are consoling, since they show how poignantly our brethren of the bar share with us the sorrow caused by the death of our cherished and venerated Chief Justice. When the shadow which the bereavement resulting from his loss casts upon the path of duty which lies before us is considered, the resolutions are additionally consoling, since they strengthen our conviction that, whatever may be our infirmities, we may always rely upon the generous judgment of our brethren of the bar if only we bring to the discharge of our duties the singleness of purpose which ever characterized the judicial labors of our late Chief Justice.

"Those labors find an enduring memorial in the reported decisions of the court rendered during the long period of his service. Their potency, whether in enforcing and protecting individual right or in perpetuating representative government by upholding our constitutional institutions, has passed beyond the influence of praise or blame. They have become the heritage of his countrymen, for whose good he labored with untiring devotion.

"The darkness of the valley of the shadow of death yet so obscures vision as to render it impossible for me to attempt now to fix the result of the labors of the Chief Justice or to define with accuracy the scope of the blessings to his countrymen and to mankind which have arisen from his work. I therefore do not attempt to supplement the brief statement on that subject which you, Mr. Attorney General, have so eloquently made. So, also, I shall forbear to comment upon the wide attainments of the late Chief Justice, his engaging literary fancy, his great familiarity with precedents, and his grasp of fundamental principles. I leave these special attributes, as well as the wider considerations which would be required to be taken into view in order to symmetrically analyze the judicial work of the late Chief Justice, not only because some other occasion would be more appropriate and some more masterful hand than mine be required to do justice to those subjects, but also because my purpose now is only briefly to refer to some of the more endearing and admirable personal traits of the Chief Justice which were manifested to those associated with him in judicial labor, and at the same time to mark the attributes from which those traits were derived and sustained.

"Briefly, those qualities were his untiring attention to his judicial duties and the dedication which he made to the efficient and wise performance of those duties of every intellectual and moral power which he possessed; his love of justice for justice's sake; his kindness, his gentleness, associated, however, with a courage which gave him always the power fearlessly to do what he thought was right, without

fear or favor. The source whence these endearing and noble qualities were derived was not far to seek. It was faith in the power of good over evil; faith in the capacity of his fellow men for self-government; faith in the wisdom of the fathers of our institutions; faith, unshaken faith, in the efficiency of the system of constitutional government which they established and its adequacy to protect the rights and liberties of the people. And, above all, there was an abounding faith in Divine Providence, the faith of a Christain, which dominated his being and welded all his faculties into a harmonious whole, causing his nature to be resonant with the melody of hope and charity, which made him what he was—a simple, kindly, generous, true, brave, and devoted public servant, treading with unswerving step the path of duty, until the tender voice of the All-Wise and Merciful Father called him from labor to rest, from solicitude to peace, and to his exceeding and enduring reward.

"Mr. Attorney General, the resolutions of our brethren of the bar will be made a part of the records of the court. In making this order the thought comes unbidden to the mind that if there be in the future, by either the bench or the bar, a failure to discharge duty because of the want of an honest effort to do so, the resolutions will become the test of our moral insufficiency and be a relentless instrument for our condemnation. But the shadow created by these misgivings is at once dispelled by our conviction that although the Chief Justice has gone before, yet doth he abide with us by his precept and example, which I can not refrain from hoping will be a spiritual beacon leading both bench and bar to a perfect dedication of all their powers to the complete discharge of their whole duty. Ah! In the luminosity afforded by that example and precept, and with the benign vision given by that faith which is the proof of things unseen, may the hope not be indulged in that the result of such a consecration to duty will enable us to behold a continued righteous administration of justice, a preservation of our constitutional government, the fructification of all the activities of our vast country for the benefit of the whole people, the abiding of tranquility and happiness in all the homes of all our land, and the continued enjoyment by all our countrymen of individual liberty restrained from license and safeguarded from oppression."

Other touching tributes to Chief Justice Fuller might be cited. They all portray an earnest, efficient jurist, a man true to the wise principles that guide the daily life of an upright American citizen who holds the exalted position of Chief Justice of the United States.

ORNAMENTATION OF RUGS AND CARPETS.[1]

[With 6 plates.]

By Alan S. Cole, C. B.

In preparing this course of lectures, which the Royal Society of Arts has kindly invited me to give on textile ornament, I find the range of subjects covered by the title much wider than I expected.[2]

Of textiles alone there are several distinct sorts: (1) Shuttle weavings, with ornament special to brocades, velvets, damasks, and figured silk stuffs, to say nothing of kindred ornament in woolen, linen, and cotton fabrics; (2) tapestries, with their decorative pictures of religious, mythological, historical, and domestic subjects; (3) carpets, with a number of simple and highly complex patterns; (4) embroidery, which is suitable to render almost any sort of ornamental and pictorial designs; (5) lace, with its textures and ornament distinctly different from those of the foregoing; and (6) stamped, dyed, and printed textiles with a still further variety of pattern and design.

The ornament of these different classes of textiles is but a chapter—an important one, certainly, but still only one chapter—in the story of all ornament, and as textile ornament during, say, 5,000 years has derived almost as many of its phases from ornament in other materials as it in turn has contributed to them, I find it necessary to take these latter also into some account. In order, then, to keep within the appointed limits, the choice of one or two central or rallying points becomes desirable, and in view of my previous Cantor lectures upon lace, tapestry, and embroidery, I have fixed upon ornament in carpets and in stamped, dyed, and printed textiles for my present course. This ornamentation has successive styles. Style is a convenient word to apply to the results of reviewing ornament designed by historic peoples, of determining various peculiarities or salient features in it, then of grouping them together and naming each group after some nation, locality, or period. In this way rough and

[1] Reprinted, by permission, from Journal of the Society of Arts, London, No. 3008, vol. 58, July 15, 1910.

[2] Lecture 1 (delivered Jan. 17, 1910) of series of three lectures on textile ornamentation. Lectures 2 and 3 are on stamped, dyed, and printed textiles.

ready classifications can be made and spoken of as Egyptian, Chinese, Mesopotamian, Greek, and other styles. Underlying all these styles are certain common factors of design. For instance, the arrangement of their particular ornamental details or devices is subject chiefly to balance, to repetition, and to symmetry. Again, ornamental details or devices in all historic national styles are either representative of actual things, such as plants, human and animal beings, etc., or are merely abstract shapes presenting no likeness to any of these things; although some apparently abstract forms are symbols to convey some idea just as others are found to have descended, through many changes or distortions of drawing, from an original which represented an actual thing. These changes or distortions occur to a marked extent in the ornament of people whose ethnography is more readily studied than their history. Take, for instance, Papuans, who produce plentiful ornament that is of the distorted character. They seem to have no regulated methods of design; at least, none so evident as those of historic nations like the Chinese, the Egyptians, the dwellers in Mesopotamia, and the Greeks, all of whom had culture, organization, manufactures, and commerce in a high degree. These great nations possessed neither aeroplanes nor telephones, but they appear to have paid better regard than many of us do nowadays to the suitable ornamentation of ordinary and ceremonial objects of use, including costumes and floor and furniture coverings.

Leaving this digression, I come now to carpets and their ornamentation. I use the word carpet in the sense of an ornamental textile to be used under foot. Broadly speaking, there are two sorts of carpet—one with a flat texture and the other with a definitely raised texture. It appears that in Egypt, Mesopotamia, Persia, and Greece flat-textured materials were manufactured long before those with raised texture. Ornament in the ancient flat-surface stuffs was produced by inweaving, needlework, painting, and stamping. In previous lectures I have touched upon the antiquity of methods of inweaving and embroidery as practiced by famous historic nations hundreds and, in some cases, thousands of years before the Christian era. The inweaving corresponded precisely with tapestry weaving by hand of the present day. Its texture was therefore the same as that of a huge Gobelins tapestry and of a Kurdish rug.

Here is an ordinary specimen of such a rug, which illustrates the flat texture we are considering. The style of its ornament has probably endured for some centuries. The scheme or plan of its design is a field of small repeated devices inclosed within a border. This scheme or plan in connection with rugs and carpets is an old one; older indeed than most of the devices in the field which are weavers' renderings of sprays of blossom and leaves; the ornament of the border is effective by reason of the repetition of its details. These

are almost unintelligible, though the original of them probably was a dragon's head; the dragon was invented by the Chinese almost as early as the Sphinx was invented by the Egyptians, and apparently some centuries before Perseus encountered any similar creature.

The next slide shows a simple but adequate frame of the sort which has been in use from old times by wandering families or groups of carpet makers in Turkestan, farther east, and south. In such a frame flat or raised surface rugs could be made. These wandering weavers have inherited, as it were, the designs they work in their rugs; and, unless they come into the service of some merchant or patron who furnishes them with other designs, they continue to produce with scarcely any intended, but with a good deal of accidental, variation of their own traditional patterns and designs. And this condition has lasted amongst such peoples for many centuries.

This slide is from the carving of a floor covering which was probably of tapestry weaving, as indeed was the greater number of ornamented textiles made by Egyptians, Assyrians, Persians, and Greeks before the Christian era. This carving was discovered in the ruins of Kouyunjik and is of Assyrian workmanship, eighth century B. C. The plan of its design, as fully displayed in the whole of the floor covering, originally corresponded with that of the Kurdish rug, having its field of pattern inclosed within a border. In this case the ornamental features of the border are well shaped, and are based upon plant forms. The outer ones are alternately buds and expanded flowers, those in the next series are full daisy blossoms, and then come repeated palm or radiating palmette forms. The pattern of the field is formed with intersecting circles, and is a truly abstract pattern, being unrepresentative of any actual things and not symbolical in any way. The texture of such a carpet was, as I have said, probably that of tapestry weaving and not of raised or cut pile. Indeed, the manufacture of this latter and more complicated material does not seem to have been known by the old Egyptian, Assyrian, Persian, and Greek weavers. The nearest approach to raised surface textiles made by them were linen cloths faced with loose loops. These give a shaggy-faced material resembling modern bath towels. Several pieces of it have been found in disused Egyptian cemeteries, dating probably from the first century B. C. or A. D., and it is considered by various authorities that they are identical with a fabric called by Aristophanes "Persis," and reputed as a manufacture of barbarians. The Greeks, however, also manufactured similar textures, and called them "kaunakes" and "phlocata." Pliny, writing 500 years later, mentions corresponding stuff as "amphimalla" when the shagginess was on both of its sides, and "gausapa" when woven on one side only. This shaggy material was apparently as common in use as tapestry weavings, but it does not seem to have lent itself

well to ornamental expression. And this I gather from specimens of it made probably by Copts, who decorated it with close loops of wool.

Here is an exceptionally good example of a shaggy-faced floor or couch cover treated in this manner. The style of the design may be called Egypto-Roman. The center is surrounded by a bordering of rectangular corner shapes linked together with intervening star forms. It is interesting to note the interlocked device within the left-hand star—a device which I think is of Chinese origin. We find it in Turkestan and Asiatic rugs, as well, of course, as the swastika or crooked cross—another constantly occurring emblem in Chinese ornament.

Of more distinctly Roman character is the design in this next example of looped worsted weaving or embroidery produced possibly by Copts in the second or third century. Here we have but a corner of a floor covering of the period, enough, however, to indicate that the whole of the field was covered with groups, like the single one here, of cupids in a boat. The border was narrow and of overlapping leaves, and a medallion, containing a face, in each corner of the whole rug.

Such a textile may represent the "Sardian pile carpets" mentioned by the Egypto-Roman writer, Athenæus, of Naukratis, a place now identified with Tell-el-Bareet, near the Rosetta branch of the Nile. Sir George Birdwood, in his treatise on the "Antiquity of Oriental Carpets," gives several interesting quotations from the "Banquets of the Learned," by Athenæus, to prove the considerable use in the third century A. D. of floor coverings—but judged by the light of fabrics discovered in the disused Egyptian cemeteries, already referred to, none seems to indicate in a convincing way that cut-pile carpets or any carpets of distinctly Eastern design were amongst the usual household goods of either Greeks or Romans. We have, I think, to look elsewhere for the earliest of such things.

Cut-pile fabrics were, I think, first produced by the Chinese. For more than 2,000 years before Buddhism reached them, they had preserved to themselves a monopoly in the cultivation, spinning, and employment of silk. It is the most delicate of all fibers or filaments for textile purposes. In the possession of this monopoly, and of a prolonged skill in the ornamental arts, the Chinese seem to have developed every sort of known process of ornamental and complicated weaving—so, at least, one must infer from their traditions and records. The evil of seclusion which had hidden these things from the rest of the world was gradually lifted by the trade started by Asiatic peoples living outside the Great Wall, who were the means of communicating to the northern districts of the old Persian Empire, two centuries or so B. C., some knowledge of Chinese manufactures and ornamental design. The trade in its course affected Asiatic crafts-

men and weavers; and they seem to have been the pioneers, as it were, in imitating fabrics similar in texture to that of Chinese velvets and the like. These Asiatics had boundless supplies of wool, camel and goat hair, long before they learned how to rear silkworms and cultivate them. Rulers of districts along the Chinese trade route recognized the value of this Asiatic enterprise in industry at places like the ancient Karakoram, Khotan, Samarcand, Bokhara, Herat, and thus cut-pile manufactures passed on to India and Persia, whose dominion had extended from Turkestan to Asia Minor and Syria, and included, of course, the territories previously governed by Babylonians and Assyrians; but there these goods were retained—the Persians being very jealous of them and preventing textile manufactures from China from passing westward over to the Romans.

The ornament in the Asiatic and Parthian rugs and carpets, such as they then were, consisted probably of geometric and abstract forms interspersed with adaptations of Chinese emblems. But about the fifth or sixth century A. D., or even a little earlier, they were combined by the Persians with devices of their own Sassanian, Roman, Persian, and older Assyrian styles. When, therefore, the Emperor Heraclius took possession of the royal castle of Dastagerd in 627 A. D., he found, among other treasures there, carpets, and most of them no doubt were of geometric and abstract ornament, and a less number of realistic ornament. But this ornamentation can have borne few, if any, direct traces of either old Egyptian or Grecian styles of ornament. It had a style of its own, and was alive in Persia up to the time when Mahomet and his conquering Arabs overran that country, Egypt, and elsewhere. It served as a base from which gradually the Saracenic or Mohammedan styles arose.

Now, for a far longer time than the life of the style we are considering, the Chinese style had been gradually influencing ornamentists with some, at least, of its variety and ingenuity of design that must have proved stimulating to all who came across it. In both abstract and realistic ornamental forms the Chinese style has always been exceedingly rich, as may be gathered from ornament on ancient Chinese bronzes. These have, of course, outlived contemporary weavings and embroideries, which would have been decorated with as much, if not greater, variety of ornament. To put before you a suggestion only of what I mean by the variety and ingenuity of old Chinese ornament such as has lasted with little intrinsic modification for 4,000 years, I have had a slide made from two Chinese bronze vases.

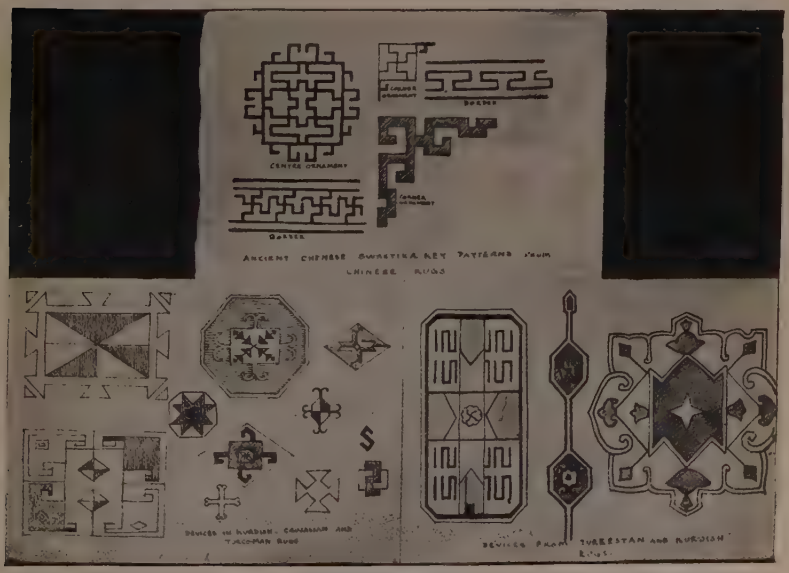
The vase on the left (pl. 1, fig. 1) is a wine vase made in 780 or 769 B. C., and is symmetrically decorated with highly conventionalized dragon and bird forms adapted to fit into given spaces. These

forms vary in size with that of their spaces, and are distributed within them with the skill of sound and well-established ornamental design. A slight obliteration has taken place in course of time and interferes a little with the definition of them, but there is nothing of haphazard or barbaric art about them. The strange forms given to the birds and dragons on the wine vase were meant as ornament; more graceful realistic forms were designed and modeled at this period, so that the strangeness is by no means due to want of ability to do better, and does not therefore imply barbaric or primitive performance. The other vase (pl. 1, fig. 2), with elephants' heads and rings, is of another phase of treatment, but one just as old as that of the conventional ornament on the wine vase. The ornament in this second vase is freer and more dainty, and some of the details are much more naturalistic. In the upper broad band about the neck are graceful, slim dragons upon a background fretted with the key pattern. About the bowl of the vase the background is of small continuous stems with spirals, upon which are large conventional forms, which, by the way, are arranged rather like those of our own seventeenth century strap ornament. Authorities say that this old Chinese conventional ornament is one of many which are intended to be emblematical of the dragon. Above it occur two Vandyke panels filled with a pointed device, which is suggestive, at least, of a lotus blossom, a detail very frequent in Mohammedan ornament done by Persians centuries later. Around the base is a band of swirling and foaming waves. These two bronzes give us at least some idea of unusual versatility in ornamental design. But besides such examples as these of the great technical skill and mature power of design possessed by the Chinese in the eighth century B. C. and much earlier, too, there are still older traditions and records of what they were doing in the ornamental arts. Some 2000 B. C., for instance, some 500 years before Joseph introduced his brethren to Pharoah, who would have been wearing a long flax tunic spotted with simple lotus buds inwoven with colored wools, the Emperor Shun's silken robes had been woven and embroidered with the 12 chang or ornaments. These consisted of (1) a solar disk upon a bank of clouds, a three-legged bird within the disk; (2) a lunar disk containing a hare with pestle and mortar pounding the elixir of life; (3) a constellation of three stars; (4) mountains; (5) five-clawed dragons; (6) variegated pheasants; (7) a pair of temple vases somewhat like one of those we have seen, but ornamented with a tiger and a monkey; (8) grass in sprays; (9) fiery scrolls; (10) grains of millet grouped in a medallion; (11) a warrior's ax, and (12) a symbol resembling two E's back to back.

It would take up too much time to go on reciting the number of other different representative and fanciful ornaments that enter into

1. ANCIENT CHINESE BRONZE VASE, WITH DRAGON ORNAMENT.

2. ANCIENT CHINESE BRONZE VASE, WITH DRAGON AND OTHER ORNAMENT.



3. ABSTRACT AND SYMBOLICAL ORNAMENTAL DETAILS IN CHINESE AND OTHER ASIATIC RUGS.

1. REALISTIC AND SYMBOLICAL ORNAMENTAL DETAILS IN CHINESE AND OTHER ASIATIC RUGS.

2. CHINESE CUT-PILE RUGS.

designs of the very ancient Chinese. Their complex rectangular ornaments of abstract and symbolical character, as well as the counterversion of them rendered in curves and spirals are, I think, even more remarkable and intricate than anything based on corresponding elements in Egyptian, Assyrian, and Grecian ornament. In all likelihood textiles ornamented with all the familiar devices were then made in China, though none probably is in existence now. Still, in view of the conservative habits of the Chinese, I think we can get from modern examples some fair idea of the appearance of ornament in old Chinese cut-pile carpets, such as are likely to have been used in north China, Manchuria, and Mongolia—as well as of modified ornament made by Asiatics along or in touch with the trade route across the Western Chinese Empire.

Plate 1, fig. 3 is from some rough sketches I have made of details in cut-pile Chinese and other Asiatic rugs. The two first are a central ornament or disk shape and a border of key pattern devised upon the swastika emblem (the crooked end cross). The same ornament is to be seen on Chinese bronzes of 1000 B. C., as well as in old Chinese enamels, where it sometimes is terminated with a dragon's head; variants made with curved instead of rectangular winding forms are similarly terminated. Swastika and dragon ornament is, I think, a possible parent of Mohammedan arabesques, which we shall come to later on. Below the Chinese details are others that I took from rugs made by weavers in Turkestan, Bokhara, and Caucasia, some in tapestry, some in close short stitch embroidery, and some in cut-pile material. The first of them is not peculiarly characteristic; the one below it with incipient key devices seems to have a Chinese flavor; near it are various cross forms, some of which are Chinese swastikas; others with scrolled limbs, as in the octagon, are perhaps of Tibetan descent. Below an **S** shape is the knot or interlocked device which we found in the Coptic Egypto-Roman floor or couch cover, and it may be symbolical of a recommendation, said to have been made by Confucius, that Taouists would do better if they gave up writing and took to making knots on strings. I am not quite clear if Confucius was satirical and poking fun at his pupils. A large panel or seal-shaped ornament contains what may be imitations of the eight trigrams of Chinese divination (Pa-Kua). The long narrow ornament, with two hexagons, may be an adaptation of a form of band that was often woven into Syrian and Egypto-Roman linen tunics about the sixth or seventh century A. D., and the last panel of later date is of semiabstract shapes and of conventional lotus buds.

The upper ornaments in the next slide (pl. 2, fig. 1) are from Chinese cut-pile rugs, and are both realistic and symbolical. The circular forms may reflect veneration for the disk; one to the left contains

an emblem of longevity, which is surrounded by bats typifying "Felicity;" the other consists of four birds—beak converging to beak; below this is part of a border that contains dragon forms like the one given here. Such ornaments existed in China long before other people knew them or tried to imitate them in any such way as that indicated by the sketches below them, which are of details in cut-pile and other rugs from Turkestan, Persia, and Kurdish districts. None of the rugs is of great age, still the ornament on them represents many conventions in rendering dragons, birds, flowers, human and animal forms, the archetypes of which were more realistic in appearance and better drawn. The part of a rug border to the left, in the lower set of details, has a conglomeration of dragon and bird forms; the bird immediately below is from another part of the same border; next to it is a bit of a carnation border—a rude version, probably of a Persian fourteenth century border; next to it is a device—perhaps a double-headed eagle, although its counterpart in other rugs looks more like a conventional fruit or flower. The childishly drawn man and horse, with many other similar creatures, frequently occur in flat and raised surface Caucasian and Kurdish rugs; and so does the curious device to the right, which, with several others, was sent me by a friend. The half hexagon panel with a dragon derivative is from a Persian cut-pile rug which has its weaver's name on it in Persian characters.

It seems to me to be within the bounds of reasonable supposition that some of these Asiatic rug ornaments are as old as the first and second century A. D., though they may have been scarcely known beyond Syria and Asia Minor. The same style of rug ornaments has continued to the present day, and I suggest that the next few slides may be representative of varieties of rug designs which have been used during the last 2,000 years perhaps.

The first (pl. 2, fig. 2) is from two cut-pile rugs of Chinese design and manufacture—stout white, blue, and gray-black wools have been used. The plan of design is a field with central circular device or disk and corner devices within the inclosing border. Such circular panel or disk (solar or lunar) placed at the center of the field appears to be a particular feature in Chinese rug design.

The next slide is from two rugs, one made in Assam and the other at Patna. Both designs show Chinese influence. The Assam rug (pl. 3, fig. 1) is covered with a swastika key pattern. The scheme of the Patna rug (pl. 3, fig. 2) is Chinese with its central disk and corner pieces, but the ornament within them as well as in the border is Assyrian in a style more than 2,500 years old.

The next slide gives a design of fuller ornament. The disk or circular device at the center is surrounded with repeated Chinese emblems; the corners have Chinese key pattern; the bold forms in the

outer border show near affinity to ornament on old Chinese bronzes; the smaller details in the field are derived for the most part from plant form. This cut-pile rug was probably made in the neighborhood of Yarkand.

Two rugs are shown on the next slide. That on the left (pl. 3, fig. 3) is of cut pile and has three disks, each of which is surrounded by curved and spiral versions of the swastika. The border has a variety of circular blossoms or emblems. This rug comes from Yarkand. The second one (pl. 3, fig. 4) has three octagonal panels instead of disks occupying the larger part of the field, which is elsewhere filled in as the border is with various more or less abstract details like those we have already discussed. Amongst them are a few Chinese symbols of simple type. The rug is of closely-stitched needlework, and is considered to be a Soumak rug, which is, I believe, a corruption of Semaka, a town in Caucasia. The work corresponds with that of some of the saddlebacks from this district.

Of less interest in the history of carpet design is that of the familiar red and green modern Turkey carpets. In these comfortable cut-pile floor coverings, the unintelligible forms are, I think, remotely related to those of the Asiatic rugs mingled with others distantly derived from patterns that were being designed before or about the time when Marco Polo traveled in Asia Minor and noted the fine carpets made there. These were doubtless of a type of Mohammedan style, the gradual development of which in Egypt on the one hand, and the Mesopotamian districts of Persia on the other hand, commenced soon after the eighth century. About then and for some time later on, Asiatic rugs such as we have seen were used at the courts of the Khalifs and Mohammedan governors in Egypt, Syria, Sicily, and Spain, whence germs only, of the later taste for rugs and carpets, were sparsely diffused in Europe.

I have already said that at a period shortly preceding the Mohammedan conquest, the ornamentation in Syria and western parts of Persia, and to some extent in Egypt, was largely of a degenerate Roman character with occasional traces of ancient Assyrian feeling. It had but little Chinese flavor, and to give you a bare impression of its character I have a few slides made from Coptic and Perso-Roman specimens.

The first is from a Coptic tapestry weaving, with an Egypto-Roman style of ornament of the fifth or sixth century A. D. picked out in needlework. It may have served as a couch or stool cover. The greater part of its ornament consists of ingenious variations of the Roman Guilloche. The intertwistings fall into repeated circles, within which are blossoms, and from such may have descended the fully developed plan of pattern seen in silk weavings of the period, in which the repeated circles were much larger and more widely sep-

arated, and inclosed fanciful griffons, lions, hunters on horseback, parrots, etc. Such patterns prevailed in Sassanian and Byzantine silks.

The next slide is from a linen fragment of Coptic or Syrian tapestry weaving. Here we have a rather rude rendering of an old Assyrian device, a tiger or lion springing on the back of an ibex or gazelle. Improved representations of it occur in Mohammedan ornament, and in Persian carpets of later date.

The next slide is from a golden bottle of the sixth or seventh century. Its main ornament, Perso-Roman in style, consists of large roundels, connected together, and inclosing such groups as the one we see of a griffon pouncing on a gazelle, which again is a reminiscence of the Assyrian device.

How handicraftsmen and designers working in this style blended it with Chinese ornament and Chinese feeling, which was so prevalent in Asia during the Tang Dynasty (seventh to tenth century), and invented much of what has become Mohammedan ornament, is the next suggestion I have to make with a view to offering some explanation of the ornamental designs in famous Persian carpets which are generally regarded as preeminent amongst all carpets. The Mohammedan Conquest dates from the beginning of the seventh century. One of the reputedly oldest Mohammedan buildings, having ornament on it, is the ninth century mosque of Tulun, in Cairo. It was doubtless the work of Copts, and I think that Coptic-Sassanian elements as well as others closely resembling in effect modified traditional Chinese patterns—those usually about an ogre's mask—underlie a good deal of the internal ornamentation of the mosque. The invention of the intricate Mohammedan geometric tracery, and interlacing ornament, including the curved arabesques that terminate in conventional foliations, seems to throw back to influences of Chinese designs having the same character of line and general scheme. The flow of Chinese influence must have become stronger than ever, when Arabs, in the ninth century A. D., were not only pushing trade with the Chinese by both overland and oversea routes, but also had business settlements at Canton and other seaport towns in China. Arab rule at this period was most extensive. Their khalifs and governors in all parts—Asia, Egypt, Spain, etc.—possessed themselves of all the material luxuries that resources and native industry could supply. Their luxurious indulgence is the topic of many of their records; and from a single instance such as that of Ahmed Tulun's son, who had in his palace at Cairo a lake of quicksilver, upon the surface of which "lay a feather bed inflated with air fastened by silver bands to four silver supports," one can imagine how superbly they had the best of things; and, as history tells us, were rightly looked upon—not only in Europe but in China and amongst the Hindus and Tar-

1. RUG WITH SWASTIKA KEY PATTERN FROM ASSAM.

2. RUG WITH CHINESE SCHEME OF DESIGN FROM PATNA.

3. CUT-PILE RUG FROM YARKAND.

4. NEEDLEWORKED RUG FROM SHEMAKA, IN CAUCASIA.

1. PERSIAN METAL BOWL, WITH MOHAMMEDAN ORNAMENT.

2. PERSIAN METAL EWER, WITH MOHAMMEDAN ORNAMENT.

tars—as the richest princes in the world. Their religious tenets formed the basis of that uniformity of taste with which they required the art craftsmen who served them to comply, and the earlier of these artificers and ornamentists appear to have been Copts in Egypt, and Persians in Mesopotamia. The Arabs themselves were not, during the first periods of Mohammedanism, artistic craftsmen, although they were builders. As regards the output of carpets about this time we have, I think, to look to the weavers in Syria, Armenia, Mesopotamia, Persia, Bokhara, and Turkestan, whose ornament was chiefly of a geometric style, with Kufic inscriptions. About the beginning of the thirteenth century the Mogul ruler, Jenghis Kahn, "a true leader of man," deported thousands of men of arts and crafts from their homes at Samarkand to work in distant part of his realm for his princes and nobles. "This," the historian writes, "was the beginning of the Mogul system of recruiting by force, of compelling the service of artisans, of confiscating industries for the benefit of the nation." Besides his military exploits and his zeal in public works, he gave new impulse to the trade with China. Soon after, his great nephew, Mangu, became Kahn, and lived in splendid comfort in his capital at Karakoram (long since gone to ruin) in south-east Turkestan—where in front of his throne was placed a silver tree having at its base four lions from whose mouths there spouted into four silver basins, wine, kumis, hydromel, and terasine. At the top of the tree a silver angel sounded a trumpet when the liquors ran short—another instance of Mohammedan luxury which is hard to beat even now. Halagu Kahn, also a great nephew of Jenghis Kahn, undertook big expeditions, and amongst other places captured Bagdad, which still retained fine traditions of Haroun-al-Raschid's flourishing times. Accompanying Halagu were hundreds of Chinese artificers, who are sometimes spoken of as engineers only, but for all that I think it more probable that amongst them were workmen proficient in branches of ornamental industries, and that they introduced some fine Chinese ornament into the metal mounting of the spheres, astrolabes, and globes which Halagu's astronomer set up at Bagdad.

At this time we get indications of high achievements in branches of Mohammedan art—notably so in the metal work, the earlier bits of which are considered to have been made at Mosil, on the Tigris, some 200 miles northwest of Bagdad, whose glory was then on the wane. The ornament of this metal work has a considerable bearing upon that of rather later Persian carpets. With its arabesque key patterns, scrolls, hunters, animals, inscriptions, and floral devices, it is the exemplar of a Mohammedan style that passes on from phase to phase between the thirteenth and seventeenth centuries, with so little change that it is difficult to classify them according to locality

or period. Some are more restrained and simpler than others, though all have the same air de famille. The simpler ornament was in accordance with the tenets of orthodox Mohammedans. At an early date in the spread of their religion the Prophet's followers had divided themselves into two parties. Persians belonging chiefly to the Shi-ite and more easygoing sect, while the Sunnite or orthodox sect comprised Egyptians, Copts, and Moors, as well as some of the peoples in Asia Minor and farther east, who in the making of their rugs and carpets inclined almost exclusively to semiabstract and geometric ornament such as we have seen. The existence of the two sects helps, no doubt, to explain the maintenance in oriental carpets of the two divisions of style in Mohammedan ornament. In both we find traces of Chinese influence.

And now let me put before you two slides made from examples of the metal ornament, and point to Chinese details in them.

The first example is from a casket rich in symmetrical ornament of delicate stems that intertwine and form panels, the most of which are filled with an interlocking angular pattern, the basis of which is a developed swastika device. The intertwisting stems may be descended from Coptic interlacements, but the swastika patterning is surely Chinese. The leafy scrollwork, with birds here and there, throws back to Chinese and Perso-Roman origins. The two winged figures on the feet of the casket are Perso-Roman or Sassanian, though the idea of such fantastic creatures may have come into Mesopotamia from China or Egypt centuries earlier.

The next slide is from a bowl and ewer, also of the thirteenth century, possibly from the hands of art craftsmen farther east in Persia, as at Ispahan. The ornament on each of these objects includes figures, and thus is more to the taste of unorthodox Mohammedans. Sportsmen hunting all sorts of strange creatures, mostly winged, and these in turn attacking others, together with griffons back to back, are to be seen in repeated four-lobed panels, between which is a ground of Chinese key pattern. Bands of foliated arabesque scrollwork run under the rim, round the center, and at the base of the bowl. (Pl. 4, fig. 1.)

The ewer (pl. 4, fig. 2) is decorated with kindred ornament though different in design, especially the shaping of the compartments on the lower part. These are formed by intercrossing bands of rope ornament, and resemble some of the enrichments in the ninth century mosque of Tulun, but their shape is also akin to that of the pointed device which we saw in one of the Chinese bronzes of much older style. The spout is a Chinese dragon head, whilst the head on the handle is that of a hound. But I will not encroach on your attention to expatiate upon the delightful cross-breeding in ornament which these objects exhibit.

The contemporary richly colored illuminations of Mohammedan MSS. and of book covers reflect the style of the engraved and damascened metal work. And from both are directly descended the compositions of color and form which are woven in the more magnificent cut-pile carpets that were manufactured in Persia from the fifteenth century onward. They practically superseded the carpets of simpler design during the fourteenth century and earlier.

The first of my slides, to illustrate a few of these finer types, is from a carpet possibly of fifteenth-century manufacture. Silver threads are inwoven with the colored cut pile of fine wool. The border of cartouches inscribed with Persian characters incloses the field, at the center of which is a circular device which, as we have seen, is a feature of Chinese and Mongolian rug designs. At each of the inner corners of the borders are segments of Persianesque panels shaped and treated so as to suggest the shape of a conventional lotus flower. Within the central circular band is a four-lobed ornament—each lobe containing a peacock, which is a favorite subject of Persian and Mogul Indian ornament. Over the main part of the field are many long and short wavy devices usually identified as Tatar cloud devices and of frequent occurrence in Chinese ornament.

The next slide (pl. 5, fig. 1) exhibits a carpet with a border of cartouches having inscriptions of which an interpretation, as given in the great Viennese work on oriental carpets, mentions the Shah, for whom the carpet was made, and states that "within the fair border of this field you see a flowery bed, refreshing and lovely as the paradise in Eden. To Chinese art its beauty is an object of envy." (This is clearly an indirect though palpable acknowledgment of the superiority of Chinese art, as known to the Persians.) And then follows a good deal more about the garden, and turtledoves and nightingales. But on looking into the design itself, at the center of the field we see a group of four lions, nose to nose, surrounded by fine spiral stems and Tatar clouds. At the top and bottom of this group is a pomegranate inclosed by two serrated long narrow leaves, charged with small sprays of flowers precisely like those on so-called Rhodian plates, and inside the pomegranate are a pair of peacocks. Beyond is a symmetrical distribution of fanciful floral ornament, lions, tigers, or cheetahs springing on antelopes—nothing in fact to suggest the serenity of flowers and birds referred to in the inscription, which may have been by chance the handiest, though not the most apposite, for the weaver to use.

The next slide (pl. 5, fig. 2) is from a carpet made in 1540 for the mosque at Ardebil—a town in the northwest of Persia and not far from Caucasia and the southwestern shore of the Caspian Sea. The wider part of the border is designed with alternating circular cusped panels and elongated panels, not inscribed but decorated with flowers

and Tatar clouds. In the center of the field is a large cusped medallion or roundel, containing dainty arabesque ornament; around the medallion is a series of pointed oval-shape panels, each filled in with floral and arabesque or Tatar cloud devices of different design. From the central pointed oval panel hangs an elaborate mosque lamp amidst flowered blossoms growing on delicate stems arranged in spirals, straying symmetrically all over the chief part of the field. Close to the lower border is a white rectangular panel with the name of the maker of the carpet. At the corners within the border are segments as of the great central ornament. The narrow light bands of the whole border are enriched with repeated Tatar cloud devices. Of its kind this is probably the most remarkable carpet, and was made nearly 50 years before the accession of the great Shah Abbas to the throne of Persia. During his reign the arts were much encouraged at his capital of Ispahan and at other important towns of eastern Persia. It is hardly possible now to identify the manufacture of carpets of Perso-Mohammedan style with any particular town of central and eastern Persia. Several fine carpets were made from 760 to 1258 in western Persia or Mesopotamia—at Bagdad for instance, for luxury-loving Abbasid Caliphs. The ornament of these, however, was chiefly geometric (as in pl. 3, fig. 4), if one may judge from Persian miniatures in the British Museum, of which I find a number quoted by Mr. Martin in his big work on "Oriental Carpets."

This is part of a Persian carpet perhaps, from Herat, with a border designed in a different style from what we have hitherto seen. The large arabesque curved forms between the pairs of varied pointed oval panels remind one of Chinese forms sometimes used in that ancient ornamentation composed with goggle-eyed ogre masks, which I have mentioned already in connection with the mosque of Tulun. The field of this carpet contains the wavy Tatar cloud shapes and several animals, the design of which seems to be Chinese in character—as, for instance, the beast on the left with curious almost dragon head and a lashing tail; there is a smaller version of him within a pomegranate form below. Still lower down is a black panther, perhaps springing across a similar dappled beast. Above, on the right, is a dappled stag with antlers. Stags and fawns are favorite animals in Chinese porcelain of the Ming dynasty (1368–1644).

Here is another variety of design in which Chinese influence seems to me to be very strong. The border is of delicate arabesque design; within the counter-changing and almost lotus-shape compartments the group of the leopard or cheetah seizing an antelope or goat is repeated. But on the field are many devices, the like of which our previous designs have not given us; for example, the highly decorated vase or bottle toward the center with a pair of Kylins at its foot,

1. Persian Cut-Pile Carpet of Late Fifteenth or Early Sixteenth Century Design, with Inscriptions.

2. Part of the Cut-Pile Carpet Made in 1540 for the Mosque at Ardebil, NW. Persia.

1. SPANISH CARPET OF LOOPED WORK, SIXTEENTH CENTURY.

2. SPANISH CUT-PILE CARPET, SIXTEENTH CENTURY.

3. ITALIAN CARPET, SEVENTEENTH CENTURY; WOVEN AT PESCOCOSTANZA.

the minute serrations to the pointed oval and circular cusped shapes inclosing birds or fishes, the cone shape, and the minute floral forms throughout, all these seem to tell of a Chinese Mohammedan designer.

This carpet is less strong in Chinese influence, but even so we do not lose it. As compared with what we have seen, the design of the field is remarkable for cypresses, almond trees in blossom, rose trees, birds perched amongst their branches, hares by their trunks, at the center ducks apparently, and at each corner a flying phœnix—the mystical Chinese bird with elaborate tail. All these are brought into ornamental effect by symmetrical arrangement chiefly. The border, like that of the immediately previous carpet, is of counter-changing, semilotus-shaped compartments, within which is delicate conventional flower ornament.

Here, again, is part of a carpet of somewhat similar design, with trees and animals—the dragon is by the trunks of the cypresses, a flight of cranes amidst Tatar cloud devices fills the cusped center panel. It is a pity that the upper part of this carpet, which came from a synagogue in Genoa, has been so cut as to destroy practically a corner panel, in which there was the figure of a man apparently in Chinese dress, and by him some unusual ornament of Chinese style—quite different from the arabesques of the border. The flight of cranes recalls the class of subject for which the Chinese painter, Hsieh Chi, of the seventh century, was renowned. The carpet was probably designed and woven in north Persia about 1450.

With the Persian carpet designs fresh in our eyes, I may now show a slide from one of the several so-called Polish carpets. Its design is of a purely Persianesque type, but somewhat angularized and stiffened in appearance. The materials are silk pile or velvet intermixed with gold and silver threads. The question of its Polish origin is one of many raised for discussion which does not lead anyone far on the road toward understanding material and artistic excellences. As far as I can find out, there were certainly some Persian or Turkish weavers in Poland in the eighteenth century who made golden brocades for a short time. The specimen before us is apparently of earlier manufacture, and may perhaps be, Dr. Bode, of Berlin, has suggested, of Turkish manufacture—one of the rich Damascus carpets in which the Venetians traded in the sixteenth century.

Rather poor in character of design is this cut-pile carpet, which may be of Moorish manufacture, to conform to the taste of some orthodox Mohammedan customer. The cruciform panel is poorly shaped when compared with Persian panels. The ground is covered with inscriptions of the ninety-nine names of Allah. The stars in

the border are suggestive of Cairene and Moorish titles of indifferent quality. The carpet came from a mosque at Aleppo.

In the same class of debased ornament, derived from finer originals, we may place this carpet. Most of the forms are undecipherable. A cypress tree is fairly evident; below it to the left is a queer and somewhat entangled device, which I think we may call a dragon; still lower down, to the left, is a pair of shapes which faintly resemble those of animals, and to the right of them is an equally faint resemblance of a long-necked bird—possibly a crane. The carpet is called Persian of the sixteenth or seventeenth century. Another specimen elsewhere is described as being made before the fifteenth century. The scheme of the design is usually found in woven stuffs of the fifteenth century, with details and devices of intelligible beauty. I think that the indications are in the direction of establishing such carpets as the one before us as ambitious attempts by careful weavers far removed from properly drafted designs and relying, therefore, upon elusive memories for their ornamentation which does not call for much admiration.

The strenuous itinerant instrumentalist seated on the pavement, and diligently twanging the strings of his harp with some rhythm, much discord, and uncertain melody is surely a kind of confrère of these weavers of distorted patterns.

This slide is from two carpets of Indian manufacture at Malabar, the modest patterns of which—especially that on the right hand—are directly borrowed from inlaid work of the fifteenth century, done by Mohammedans at Broussa, in Asia Minor, and in Venice, etc. A similar style of pattern occurs on carpets made at Tanjore.

A considerable number of Persian carpets were made in the sixteenth century from designs, of which the leading feature was a covering network or framing. Here this feature is carried out so as to produce a succession and series of interchanging panels, each of which is filled in with plant forms, Tartar clouds, arabesques, or pairs of birds. Schemes of net pattern, but in other variations may be traced in Roman mosaics contemporary with Coptic tapestry weavings, as well as in Byzantine shuttle weavings, thence they pass into mediæval European textiles and embroideries, and architectural enrichments, before appearing in carpets.

Another and simpler example of this scheme of design is shown in this next slide from an Indian or Persian carpet of the sixteenth or seventeenth century. The border is much narrower; the net or framework is defined in delicate spiral stems, and at their junctions are variously shaped panels, the network itself does not form such recurrent panels as in the previous specimen, but is independent of those here shown.

From these I pass to specimens of another type of design. That on the left is probably of Caucasian or Kurdish weaving, and in the style of fiteenth century carpet designs, whilst that on the right is of Spanish or Moorish work. Its field is covered with a diaper pattern of small foliated crosses, and toward the middle there are two eight-cusp circular panels containing a shield of arms. The outer border has Kufic characters mixed with small animal, bird, and blossom devices, which are repeated in the squares of the narrower inner border. The border pattern of the left-hand rug seems to be of ornament developed from Kufic writing, and such borders are seen in Persian miniatures dating even from the end of the fourteenth century, and more often in later miniatures as well as in paintings by such artists as Hans Memling (1425–1490), Raphael (1483–1520), and many more at this time. Such carpets, with others coming into general use by the well to do in Europe, served more often as table than as floor coverings, and it is claimed that some of them were made even in England.

Here, for instance, is one of these carpets. The design of the border corresponds with that we have just discussed; at the sides and bottom of it are shields with the arms impaled on them of two English families, and on the lowest part of the carpet are the words, "Feare God and keep His commandments. Made in the year 1603."

At this time East India merchants caused carpets to be made to their order at Lahore and elsewhere, and their coats of arms and initials would be introduced into the designs. A very fine specimen of such carpets belongs to the Girdlers' Company, and has been illustrated in recent books about carpets.

On the ornamental side of carpets made in Europe from the sixteenth century onward, there is much to say. On the gradual development of European methods of carpet manufacture there is still more to say; but in these lectures I can give an extremely brief résumé only of a few incidents that stand out. The oldest of them has to do with those French corporations of *tapissiers* whose thirteenth century regulations are well known and have been much discussed with the object of determining which of the two bodies—the "Tapissiers Sarrasinois" and the "Tapissiers Nostrez" were concerned with the manufacture of flat-surface floor covering and that of raised pile. Their weavings were employed for seats and hanging on walls, or placing on tables, and this more often probably than as floor coverings—rushes or mats being then ordinarily strewn on floors. Illuminated MSS. supply indications of their patterns, which were generally diapers and spottings; patterns of fuller design were displayed upon imported Oriental carpets. With the early years of the sixteenth century the manufacture of tapestries in France begins to be organized, under the patronage of the Government, but it is not

until the seventeenth century that pile-carpet making, under this patronage, is well started at a disused soap factory known as the Savonnerie of Chaillot, on the outskirts of Paris. Here were made the *tapis veloutés*—pile carpets as distinct from the *tapis ras*, or flat-surface carpets that were being produced at several of the tapestry weaving centers—the Gobelins, Beauvais, Tournai, etc. The manufacture of the two sorts was not combined at the Gobelins works until early in the nineteenth century. Aubusson carpets were first made early in the eighteenth century from designs that reflected the Louis XV. style—naturalistic floral garlands, ribbon knots, all shown with lights and shades, and entirely distinct in style from that of any Oriental rugs and carpets.

In Spain some rugs are likely to have been made at many of the old Moorish towns, Malaga, Almeria, and Granada, perhaps as early as the middle of the ninth century, when their ornamentation would have been probably of the geometrical and abstract character, intermixed with inscriptions that appealed to Sunnite Mohammedans. Toward the end of the fifteenth century Spain had much to do with Flanders, where tapestry weaving was flourishing; it appears that at this time the making of Spanish carpets as distinct from Moorish carpets began. Specimens of them have come lately into collectors' hands, some with cut pile, others with looped surface similar to those Egypto-Roman stuffs that we saw at the beginning of this lecture, and others wrought in a sort of cross-stitch embroidery.

Here are now two of the Spanish rugs I have in mind, made probably in the sixteenth or seventeenth century, one (pl. 6, fig. 1) with a surface of loops has an ogival net or frame of vine stems with symmetrical groups of leaves and grapes alternately placed in the ogival panels. The scheme of the design is Byzantine originally, and became finely developed in Italian velvets of the fifteenth century. The border of this carpet is of a continuous stem scroll with offshoots of conventional plant shapes. The other carpet (pl. 6, fig. 2) is of cut pile of fair quality, its field of three octagonal panels or wreaths inclosing scroll ornament with a slight resemblance to Saracenic arabesque disposed on the plan of a cross, has a border of Italianesque scrolls, griffons, and baskets. In both carpets the corners of the borders are not well managed in design—a defect which is seen constantly in Oriental carpets other than Persian, and runs through ornamental textiles woven from insufficient drafts, the completion of which is left to chance that the weaver can supply the deficiency of design.

The weaving of pile and other carpets in European countries from designs by Europeans arose more or less simultaneously in Spain, Italy, France, Flanders, and England, about the middle of the sixteenth century. The English industry was stimulated a great deal

through commerce with the East Indies and by the employment of Flemings here. But, besides this, a few enterprising Englishmen sent trusted workmen to Asia Minor to learn the methods of making "Turkey carpets." Nowadays, when museums expound technical and artistic efforts, progressive and otherwise, material facts are becoming available in an almost unexpected way to illustrate allusions and records, and thus give reality to much that has been speculative.

Unquestionably of English manufacture, or, more correctly, of manufacture in England, is the pile carpet shown on the screen. Details of its ornamentation may throw back to Oriental sources, but the coats of arms are distinctively British. In the center are the royal arms, with a date 1570 and E. R.—Elizabeth Regina. On the left are the arms of the borough of Ipswich and on the right the arms of a Suffolk family. Other equally interesting examples have lately become available for consultation, so that no doubt we shall soon learn a good deal more of English carpet ornament than we know at present. Carpet making at Wilton and Axminster dates from the end of the seventeenth century, and its history from that time forward can be pretty clearly traced. Many Frenchmen were employed there and elsewhere in England during the eighteenth century, and introduced much of the French taste in carpet ornamentation. The Society of Arts, as early as 1758, gave prizes for English-made carpets, "in imitation of those brought from the East, and called Turkey carpets;" and the Transactions of the Society of 25 years later record how the manufacture of these was then established in different parts of the kingdom, and "brought to a degree of elegance and beauty which the Turkey carpet never attained."

It is not difficult to make a pretty close guess of what large Georgian carpet designs were like. Some of them at least had a flavor of the French taste, and of that I have one interesting design, made at the beginning of the eighteenth century by Robert de Cotte, for a pile carpet woven at the Savonnerie. It is rather like a ceiling decoration and apropos to a style that the machine-made patent Axminster and other carpets have been affecting during the last few years, presumably to the content of some people, who do not care for the restrained treatment of ornamental forms and harmonious colors in Oriental carpets.

As to Italian carpets I have not collected much information. Shuttle weaving by peasants in the Abruzzi continues to the present day and is responsible for most of their bright-colored woolen aprons with stripes that are broché or woven with floating threads. This same character of work has been done for some centuries. In the fifteenth and sixteenth centuries Perugia was notable for white linen tablecloths and towels, broché with blue threads in a considerable variety of interesting patterns. Farther south Pescocostanza appears to have

been noted in the sixteenth and seventeenth centuries for similar shuttle-woven woolen rugs, of one of which I have a slide.

The style of the broché ornament is virtually the same as that of the Perugia linens. In the specimen now before us we have a field broken by garlands into repeated compartments, in which are, respectively, fountains, lions, horses, or perhaps unicorns, lambs of God bearing the cross and a flag, double-tailed mermaids with mirrors in their hands, and double-headed eagles, of a seventeenth century type, though almost all of them are emblems with traditions behind them, that, in some cases, spring from Gnostic sources of more than a thousand years earlier. Emblematical ornament, however, is far too big a subject to discuss now. The border of the carpet is a woven imitation of Italian lace points or Vandykes of the late sixteenth century.

The last slide is from two pile rugs made at Merton from designs by the late William Morris. In both of them we trace his regard for Oriental symmetrical arrangement and flatness in treating ornamental devices.

In conclusion I must mention my indebtedness to important publications, amongst which are the late Dr. Bushell's handbook on Chinese Art, Mr. Martin's admirable work on Oriental Carpets, and the great Viennese publications also on Oriental Carpets. This latter work contains illustrations of a hundred carpets or rugs, each of which Dr. Alois Reigl has described in detail with unsparing care.

I do not think that either of these two last-named authorities, or even Dr. Bode, of Berlin, and others, who have a profounder erudition than I can pretend to, have paid enough consideration to the enlivening effect which Chinese ornamental design must surely have had for the last 2,000 years at least upon that of other nations west of China, and especially in regard to its share in the invention of Mohammedan ornament. In offering a few hints upon that matter I hope that I have not made too great a call upon your attention. Mohammedan ornament, whether to the Sunnite or Shi-ite taste, plays a very important part in carpet ornamentation. The more it can be investigated and appreciated the less likely are we to manufacture carpets with quasi Oriental patterns that are at times really ludicrous in their simple-minded imitations of distorted devices.

It is extraordinary what modern machinery can do in producing carpets of any sort of design. Certainly the daintiest that I have seen recently were manufactured at Glasgow and are reproductions of some of the finest and most intricately patterned Persian rugs.

Messrs. Maple and Messrs. Warings have kindly lent the specimens of English machine-made rugs, as well as interesting portions of handmade carpets, not only from England, but from other European countries as well.

RECENT PROGRESS IN AVIATION.[1]

[With 19 plates.]

By Octave Chanute,[2]

Honorary member of Western Society of Engineers.

[Remarks by President Allen introducing Mr. Chanute: It is a remarkable coincidence that just 12 years ago this evening—October 20, 1897—Mr. Chanute gave his first paper before this society on the subject of aviation, the paper being entitled "Gliding Experiments." A few years later, in 1901, and again in 1903, Mr. Wilbur Wright appeared before the society, at Mr. Chanute's invitation, and gave an account of the experiments then being made by himself and his brother Orville. The opportunity comes to very few men, I think, to appear before the same body 12 years after their predictions had been made, and be able to point to the fulfillment of those predictions, as can be done by Mr. Chanute to-night.

It is our privilege to listen to him now, at a time when aviation has become a matter of great public interest, and when he can point to the fulfillment of his own prophecies, and the launching of the aeroplane as a practical machine on the ideas that he enunciated in our rooms 12 years ago. Mr. Chanute is well known to us all and needs no introduction from me. We are proud to number him among our members as, perhaps, the foremost living authority on aviation to-day in this country or in any other country.]

I shall endeavor, with the aid of some lantern slides, to talk to you about what has lately been accomplished with flying machines. As your president has said, on the 20th of October, 1897, I had the honor of presenting to you an account of some gliding experiments that were carried on at Dune Park, near this city. Those experiments were made solely to study the question of equilibrium and to determine if it was reasonably safe to experiment. We had the good fortune to make about 2,000 flights (Mr. A. M. Herring, Mr. W.

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[1] Reprinted by permission from Journal of the Western Society of Engineers, Chicago, April, 1910. Presented before the society October 20, 1909. Journal copyright 1910 by the Western Society of Engineers.

[2] Mr. Chanute died November 23, 1910.

Avery, and myself) without any accidents—not even a single sprained ankle. The only thing we had to deplore was the fact that my son, in making one flight, tore his trousers. An account of these experiments was published in the journal of this society for October, 1897, and subsequently an account was also published in the Aeronautical Annual, Boston, in 1897. That publication contained the statement that it was thought that these experiments were promising, and I gave an invitation to other experimenters to improve upon our practice. That invitation remained unaccepted until March, 1900, when Wilbur Wright wrote to me, making inquiries as to the construction of the machine, materials to be used, the best place to experiment, etc. He said that he had notions of his own that he wanted to try, and knew of no better way of spending his vacation. All that information was gladly furnished. Mr. Wright wrote me an account, subsequently, of his experiments in 1900, which gave such encouraging results that each year thereafter the brothers carried on further experiments in North Carolina and at Dayton, Ohio.

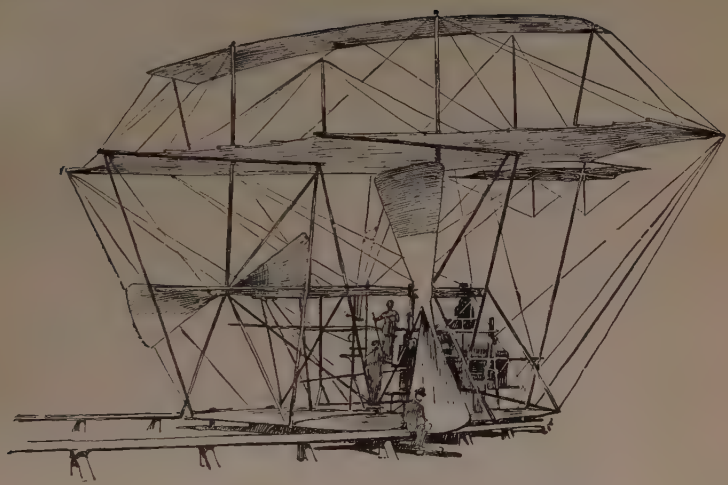
On the 18th of September, 1901, Wilbur Wright read a paper before this society, in which he gave an account of what he had done up to that time.

Again, on the 24th of June, 1903, Mr. Wright read a second paper before this society, giving an account of his progress since 1901. Late in the year 1903 the Wrights applied a motor to their gliding machine, which by that time they had under perfect control, and they made their first flights on the 17th of December, 1903. (I might mention that I was present on each of the years during part of the experiments.) At that time Wilbur Wright expressed his intention of giving to this society the first technical paper on the subject which he furnished to anyone. He said he had already promised to give a popular account in the Century Magazine, but that a technical paper, giving an account of the results and the laws which had been observed, would be reserved for this society.

In 1905 Mr. Wright told me it had dawned upon him that there was some money to be made by selling the invention to governments for war purposes, and that he would defer giving a technical paper to our society. He considered that his invention would be more valuable if, with the machine, he could give the secrets of construction and laws which have been observed. I do not know whether the paper has been written, but I hope you will get it some day.

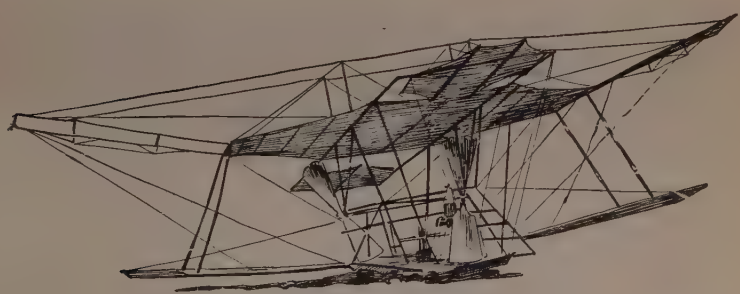
Of the early flying experiments which had been made previous to that time I will mention but two.

Plate 1, figure 1, represents the Maxim machine of 1894. Mr. Maxim built an enormous apparatus, weighing 8,000 pounds and spreading 4,000 feet of surface, moved by a steam engine of 360 horsepower. That machine was run upon a track of 9 feet gauge a good many



1. MAXIM'S MULTIPLANE 1894—FRONT VIEW.

Weight, 8,000 pounds. Propelled by 363-horsepower steam engine. Span, 126 feet; area, 4,000 square feet; cost, $200,000.



2. MAXIM'S MULTIPLANE, 1894—SIDE VIEW.

When run on rails at Baldwyn's Park, England, July 31, 1894, at 36 miles an hour, this machine lifted so much more than its weight that it broke a set of rails provided to hold it down, and thus demolished itself.

LANGLEY'S 25-POUND TANDEM MONOPLANE, 1896.

Wings at dihedral angle. This model on May 6, 1896, flew for more than half a mile over the Potomac River, at a speed of about 20 miles an hour. Subsequently, on November 28, 1906, with a similar model weighing about 30 pounds, a three-quarter mile flight at about 30 miles an hour was achieved. The size of the heavier model was a little over 12 feet from tip to tip with a length of about 16 feet.

times, and on one occasion it undertook a vagabond flight on its own account; its equilibrium was bad, however, and the steam was shut off; the machine alighted somewhat broken. Mr. Maxim saw clearly that it would be necessary to change the design, and he has never rebuilt that machine.

Another view of the same machine is shown in plate 1, figure 2. It had a large aeroplane at the top and two propelling screws 17 feet 10 inches in diameter, which imparted a speed of 45 miles an hour running over the track, and it was held from rising by wooden rails of 35 feet gauge which engaged outrigger wheels as soon as the machine left the sustaining track.

Maxim is now said to be building another machine, which it is expected will be completed soon.

The next experiments were made in 1896 by Prof. S. P. Langley. After devoting some years to experimenting, he devised a working model which he started from a launching scow. The model machine flew perfectly on the 6th of May, 1896, in the presence of Alexander Graham Bell. This machine, shown in plate 2, flew about three-quarters of a mile, alighted safely in the Potomac River, and was ready to fly again.

On the 28th of November, with a similar model, Langley made another successful flight, and further launches were privately made subsequently. [For flights of 1899 and 1903 see plate 3.]

He was then urged by the United States Government to build a full-sized machine, capable of carrying a man, and he spent three or more years in doing so. That man-carrying machine was completed in 1903, and on the 7th of October of that year the launch was attempted. The machine, however, caught a projecting pin of the launching rail and was cast down into the Potomac. The operator, Mr. Manly, was upset, carried down into the river, and came very near drowning. Another effort was made December 8 and the same mishap occurred. Part of the launching ways caught the machine, and it never entered upon flight. There is no doubt, however, that if the machine had been properly launched it would have flown. The machine is still in existence. It was broken when alighting, and in picking it up afterwards, but has been repaired. It is most unfortunate that further effort was not then made to launch that machine, and that Langley was so severely criticized in Congress and by the newspapers. He was grievously balked of deserved success, and he died of apoplexy two years afterward.

The next attempt to fly with a man-carrying machine was in North Carolina on the 17th of December, 1903, when the Wright brothers effected three successful flights, the first to alight safely in history. The longest flight covered 852 feet and occupied 59 seconds, in the face of a 20-mile wind. The weather was so inclement

that they then took the machine down and abandoned experimenting for that year. There had been unfortunately some previous delays and breakages. When I went there in November to see the launching of the machine, it was postponed first by the twisting off of the shaft, and then by the breaking of the propeller, which required sending it back to Dayton in order to repair the work in the shop, but full success was attained at last. In 1904 they operated in a field about 8 miles from Dayton, Ohio, and it took them most of that year to learn how to turn a corner. The machine was slightly broken a number of times, repaired, and finally, in October, 1905, they got their apparatus under perfect control, and succeeded in making a flight of 24 miles in 38 minutes. They made 105 flights in 1904 and 49 flights in 1905. The system which they have adopted in order to avoid carrying too powerful and heavy a motor is shown in plate 4, figure 1. The machine is placed on a single rail, weights are hoisted on a derrick, and a rope is carried from the derrick with a return pulley to the machine. Upon the dropping of the weights the machine is given an impulse, this method being found to be preferable to the catapult which Mr. Langley had devised and which failed him on two occasions when trying to launch his machine. In plate 4, figure 2, is shown the machine at the inner end of the launching rail, just before it gets under motion. The launching rail is 60 feet long, and with the aid of the falling weights the machine quickly acquires the necessary velocity for rising in the air.

The years 1906 and 1907 were spent by the Wright brothers in an effort to sell their machines to various Governments. They had taken out patents in eight different countries, and they hoped to sell flying machines to war departments, together with the secrets, the tables of resistance, and all the elaborate calculations which they had made, but in each and every case the Government wanted to be shown the apparatus before buying. The Wrights refused to exhibit the machine until such time as they had a contract contingent upon their performing certain feats—notably, to fly with two passengers and with enough fuel to carry it 125 miles; that it must attain a speed of at least 36 miles an hour, maintained over a distance of 5 miles, and must fly continuously for one hour.

None of the Governments would thus contract with them. They were offered at one time $120,000 by the French Government, but they refused. They were then offered $200,000 if they would perform their feats 1,000 feet in the air. To this they said that they had no doubt that they could get up 1,000 feet but they had never done so and would not agree to the proposition.

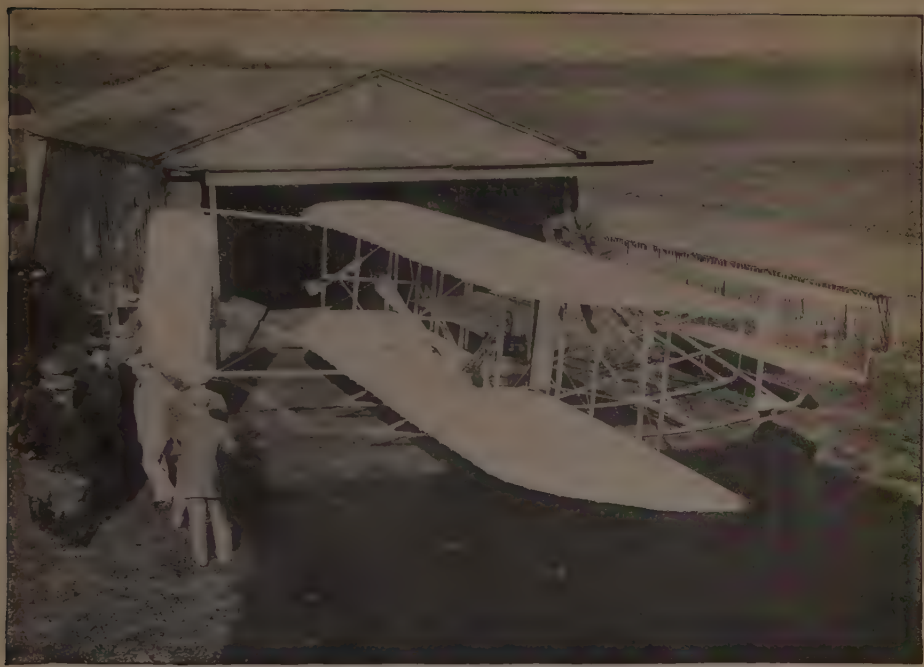
In 1908 they changed completely their plan of operation and decided to show their machine with the risk of its being copied and getting themselves into litigation. Plate 5, figure 1, shows the ma-

1. HOUSE-BOAT AND LAUNCHING APPARATUS FOR LANGLEY AERODROME, 1899.

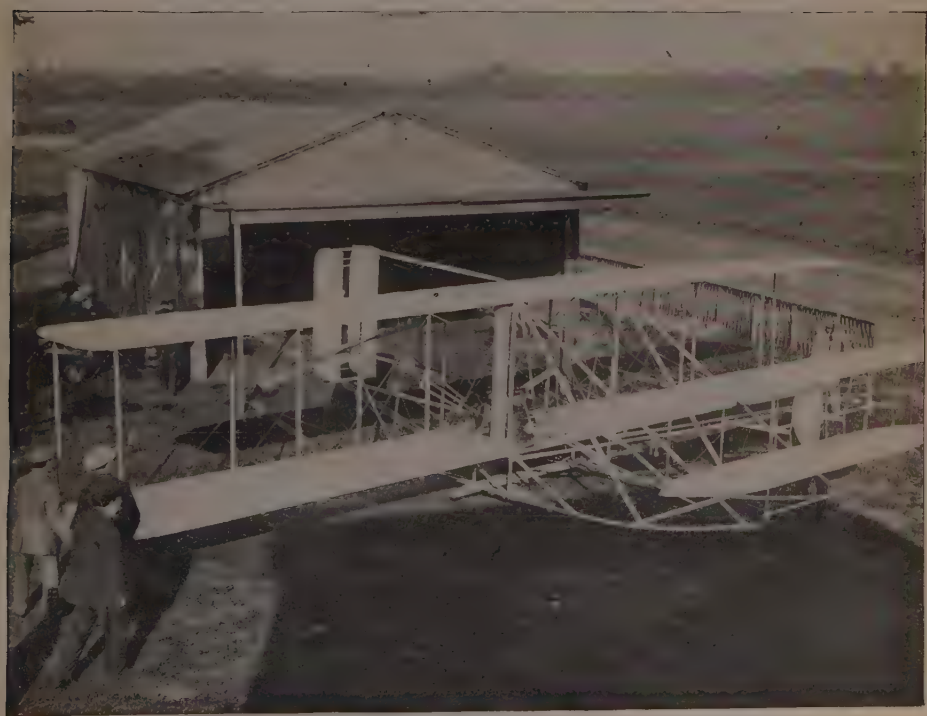
2. QUARTER-SIZE LANGLEY AERODROME IN FLIGHT, AUGUST 8, 1903.

1. WRIGHT MACHINE ON STARTING RAIL, WITH STARTING DERRICK IN THE BACKGROUND.

2. WRIGHT MACHINE ON STARTING RAIL



1. SIDE VIEW OF WRIGHT MACHINE.



2. THREE-QUARTERS VIEW OF WRIGHT MACHINE.

1. WILBUR WRIGHT FLYING AT DUSK.

2. WILBUR WRIGHT AT LE MANS.

chine of the 1908 design, at Le Mans, where Wilbur Wright first exhibited it to the French, while a contract had been made in this country with the United States Government to furnish a similar machine, and figure 2 represents a three-fourths front view of the machine. There is at the front a double-decked horizontal rudder. It will be noticed that these inventors have modified the make-up of a bird by putting the tail in front. Behind are placed vertical rudders, but it is the front rudder which elevates and gives horizontal direction to the machine. The rear rudder guides the machine to the right or left. Back of the main surfaces are the two screws revolving in opposite directions.

The machine is equipped with a pair of skids for alighting, while the French people have equipped their machines with wheels. The wheels weigh more, catch more air, and are not as safe as the skids, but the skids require a rail and a starting weight in order to get the machine into the air, unless there is a brisk head wind. Plate 6, figure 1, is from a remarkable photograph sent to me by Wilbur Wright, which was taken just at dusk.

Mr. Wright had extraordinarily good fortune in carrying on the experiments in France, his machine falling only once. One other accident occurred in the breaking of one of the sprocket chains in mid-air; but he then operated the machine as a glider and came down safely. The French people at first made all sorts of comments, criticisms, and caricatures of Wilbur Wright, and even published a number of amusing songs, but finally he triumphed, won their esteem and admiration, and they acknowledged that he was the master of all the aviators. Plate 6, figure 2, shows one of the flights at Le Mans. From Le Mans he went to Auvours in order to get better ground, and there made over 100 flights.

The more remarkable performances which he made I have undertaken to tabulate, but I will not inflict those statistics upon you this evening. Mr. Wright established great records, however. On the 18th of December, 1908, he flew 62 miles in 1 hour and 54 minutes, this being at that time the world's record, and he beat this directly afterwards, on the 31st of December, by flying 77 miles in 2 hours 20 minutes and 23 seconds, thus winning the Michelin prize and establishing a world record, which was only beaten in the tournament at Rheims three weeks ago. In Rome he took up a great many passengers, and on one occasion he started without the use of starting weights, simply facing a wind of sufficient intensity and going up straight from the ground. Plate 7 shows one of these flights. On the 25th of September, after returning to America and after he had been universally acclaimed in this country and overwhelmed (modest man that he is) with public dinners, receptions, and medals, he encircled in flight the Statue of Liberty in New York Harbor and

made a magnificent flight of 21 miles, from Governors Island to Grant's Tomb and return.

Meanwhile we may go back to September, 1908, and note some of Orville Wright's performances. He had at Washington the same general arrangement, consisting of a launching rail, launching derrick, and an apparatus for hoisting up the weights, in order to give the machine impetus. This aeroplane is 40 feet across and has a breadth of 6½ feet. The front rudder is 16 feet long, 2½ feet broad, and is equipped with skids, as shown in plate 5, figure 2. The propeller is of peculiar and original construction, and the motor is in every way the Wrights', for, in 1902, they made a canvass of the different makers of gasoline motors in this country, asking them to furnish a motor according to specifications which they presented. None of them at that time could do so, and the Wrights went to work themselves, designed a motor, and built it with their own hands. This design has proven more reliable than the motors built in France, which are unduly light. The Wright motor, originally of 15 pounds to the horsepower, was reduced to 7 or 8 pounds to the horsepower, while the French people are building motors weighing 4½ to 5 pounds, but they do not prove as reliable, while the Wright motor has never given any trouble and has proven reliable in every respect.

Orville Wright made a number of unofficial tests in 1908. On the 8th of September he rose to a height of 100 feet and flew 40 miles; on the 12th he made a little higher ascension, estimated by the Army officers at 200 feet, and flew 50 miles in 1 hour and 15 minutes. Altogether that year he made 14 flights. On the morning of the 17th of September he made several short flights. In the afternoon of that same day he met with a terrible accident; his propeller broke while he and Lieut. Selfridge were in mid-air, the machine falling to the earth, when Orville was seriously injured and Lieut. Selfridge was killed. This ended the tests of that year. The Government granted an extension of time and the trials were not resumed until July of this year (1909). The results this year, as you know, have been very successful. The official time test shows that on the 27th of July the machine remained in the air for 1 hour and 13 minutes, with two persons on board.

On the 30th of July the machine traveled 5 miles and back cross-country in 14 minutes, with two persons on board, at a speed which averaged over 42 miles an hour. Therefore, the machine was accepted by the Government and a premium was given the Wrights of $5,000 for the extra 2 miles of speed. Wilbur Wright is now engaged in teaching the Army officers how to use the machine. Immediately after the acceptance of the machine, Orville Wright went to Berlin, and there he has been accomplishing some remarkable feats. On the 29th

WILBUR WRIGHT AT ROME.

1. SIDE VIEW OF SANTOS-DUMONT'S "DEMOISELLE."

2. SANTOS DUMONT. ST. CYR TO BUC.

3. THREE-QUARTERS VIEW OF THE ESNAULT-PELTERIE MONOPLANE.
The wing wheels *b b* and the twisting rudder *h* are features of this machine.

of August last he made his first exhibition there, flying 15 minutes. On the 8th of September he went up with Capt. Hildebrandt; on the 18th of September he went up with Capt. Englehardt, and on the 17th of September he made a demonstration before the court. On the 2d of October he took up into the air the Crown Prince, who gave him a handsome present, and on the 4th of October he made a flight of 21 miles, reaching a height estimated at 1,600 feet. This is the latest performance which he has made, although there is no telling what another day will bring forth. He is now in Paris. In London he may make some demonstrations with his machine in the course of a week or two.

The French, in 1905, became partly acquainted with what had been done in this country, and they thought it would never do to let the Americans obtain priority in the air, so a good many people began to experiment. Among the first was Santos Dumont, who made a flight on the 12th of November, 1906, of 720 feet in 21 seconds with his No. 14 machine, Hargrave type. That flight created great excitement, and the French people thought they were on the high road to beat the Americans, but it required a good deal of further experimenting before that result was even partially accomplished.

Santos Dumont brought the machine out a second time but broke it. He then concluded that it was not built on the right plan and began to experiment with a modified machine. It proved unsatisfactory in various ways, and after it was broken he discarded it.

The next machine he tried was the biplane, the cellular partitions being removed. That ought, in my judgment, to have given satisfaction, but it did not and he abandoned it, although with that machine he made a flight, in Paris, on the 17th of November, 1907, of 500 feet.

He then went over to still another plan which he called the "Bird of Prey." In this design he placed the motor up in the top and had a dihedral angle in the biplane. But that did not give him satisfaction, and in the next machine he finally went over to the monoplane, which the French people have always insisted was the best design for a flying machine, and which they have promoted as against the biplane.

Plate 8, figure 1, is a view of the monoplane of Santos Dumont, and with that on the 10th of March, 1909, he made a flight of 1,300 feet. On the 10th of April he made another flight of 1.2 miles. On the 19th of June he made a flight at Issy, near Paris, of 820 feet, at which time his machine was struck by a downward rush of air, and to his great astonishment he found himself suddenly on the ground. The machine had gone down without his knowing what was happening. Fortunately the machine was not broken and he was not injured.

Santos Dumont's idea had been all along to have a handy machine, and he finally built a baby monoplane, which he called the "Demoi-

selle" (Dragon Fly). This is the smallest of all the existing aeroplanes. Its supporting surface is only 97 square feet; its weight, 260 pounds. When that is compared with the Wright machine, which has 500 square feet of supporting surface and a weight of 950 pounds (the empty machine), we can appreciate the enormous difference and the necessity, therefore, of driving this Dragon Fly very much faster in order to obtain support from the air, with so very small a surface. On the 13th of September of this year, near Paris, Mr. Dumont was able to drive that machine 5 miles in five minutes, going down the wind, or at the rate of 60 miles an hour over the ground. The speed through the air was probably about 50 miles an hour. Plate 8, figure 2, is from a photograph taken during that flight, which was from St. Cyr to Buc. I think the general idea is sound, for the smaller the flying machine can be made, within limits, the faster it must be made to go, and the more uesful it is likely to prove for varying wind conditions. Commercially I have no clear opinion as to its uses, but as a mode of rapid transportation for very light loads, I think the smaller the aerial plane the better.

As regards the question which has lately been debated extensively, of the relative merits of the biplane and monoplane, I do not think we are yet in position to decide which is the better design. Both have their good points. The monoplane offers less resistance, but the biplane is steadier, stiffer, and stronger in every way. So it is only experience that will determine which one is the most efficient.

Other experimenters have come into the field, and among the first was a clever young sculptor by the name of Leon Delagrange. He went to Voisin Bros. and asked them to build him an aeroplane. This was called the Delagrange machine, but as a matter of fact the designing and construction was done by the Voisin Bros., who are a leading authority on the subject of building flying machines, and who, in two years, have had to enlarge their shop three times to keep up with their orders.

In plate 9, figure 1, is shown the machine the Voisin Bros. built for Delagrange. At first he did not trust himself to fly the machine, but got Voisin to ride in it and show him how. Subsequently he flew in it himself and all the later feats he has accomplished by himself. On the 11th of April, 1908, he flew 2.5 miles at Issy; on the 27th of May, at Rome, 7.9 miles in 15 minutes and 26 seconds; at Milan, June 22, 10.5 miles in 16 minutes and 30 seconds. Then he went to Turin and for the first time in history took a lady on board, who was very proud of the honor. The picture (pl. 9, fig. 2) is from the meet at Rheims in August, 1909, where Delagrange flew 31 miles on a monoplane. It may be remarked incidentally that there have been lately quite a number of these tournaments in Europe, which have attracted great crowds, have proved very satisfactory, and where all

1. DELAGRANGE ON THE VOISIN MACHINE.

2. DELAGRANGE ON A MONOPLANE.

1. HENRY FARMAN'S BIPLANE IN FLIGHT.

2. FARMAN'S NEW MACHINE WINS FIRST PRIZE.

previous records have been smashed. One was at Rheims, where the Champagne people contributed large sums for the experiments. Another tournament took place later in Berlin, and still another in Juvisy, near Paris, in October, 1909.

The next man to gain prominence was the celebrated sportsman, Henry Farman, who walked into the Voisin shop one day and ordered an aeroplane. He succeeded on the 26th of October, 1907, in flying 253 feet, which at that time was considered a great feat. He then attempted to sweep a circle, but did not succeed. It really took the French people two years to learn how to turn a corner. They were somewhat misled at first by a mathematical equation, and then closely analyzed the motions of the bird. They found that he flexed one wing at a lower angle than the other, placing himself thereby on a slant, so that the centripetal force of gravity should overcome the centrifugal force of the speed, and that similar effects could be produced by side fins and wing tips. Since that time they have turned corners without great difficulty but only on long radii.

Mr. Farman was successful, among other things, in sweeping curves on the 6th of July, 1908, when he flew 12 miles in 19 minutes and won the Armengaud prize which had been offered for the first turning of a corner. One of his flights is shown in plate 10, figure 1. On the 30th of October he made the first cross-country flight in history by going from Chalons to Rheims, 17 miles in 20 minutes, thus winning great applause and becoming the foremost aviator in France. In 1909 he designed and built a flying machine of his own with which to compete at the Rheims tournament. He put both skids and wheels in this, the wheels being so adjusted that they could be lifted up, and with that apparatus splendid results were obtained in the Champagne tournament. The apparatus is shown in plate 10, figure 2.

On the 18th of July that machine flew for 1 hour and 23 minutes at Chalons. On the 23d of July he took a cross-country trip covering 40 miles from Chalons to Suippe. On the 27th of August his machine made a flight of 112 miles at Rheims, which is the world's record for distance at present,[1] and he received, therefore, the first prize in that tournament. On the same day the machine flew 6 miles in 10 minutes with three persons on board, this being the first time three persons had ridden in a flying machine.

The next experimenter to be mentioned is Louis Blériot. He began his experiments in 1906, and has built and broken more machines than any other aviator in the world. He has built 12 machines and broken about 15, that being accomplished by rebuilding the same machine after smashing it. He is a man of tremendous pluck

[1] Since this talk, Mr. Farman made, on the 3d day of November, 1909, a flight officially estimated at 137¼ miles in 4 hours 6 minutes and 25 seconds, but really of 150 miles, over the aviation grounds at Mourmelon.

and wonderful imagination, and therefore tries all sorts of things. The machine with elliptical cells was launched on floats in the Seine in order to haul it up as a kite, and was Blériot's third. He had an idea that this elliptical arrangement would increase the stability very much, but it did not, and he gave up that idea. He then constructed No. 4, which he called a box plane.

Machine No. 5 was of the Langley type,[1] on the same plan that our Army officers had been unable to obtain further funds to experiment with—two sets of wings, one behind the other—he placed it on wheels, and with that type he got some very fair flights, flying 474 feet [Aug. 6, 1907]. That was not enough for him, so he went from that to the monoplane and he has built, I think, six of them. Since then he has adhered to the so-called dragon-fly plan and is now flying on No. 12. On the 13th of July, 1909, he flew 27 miles in 45 minutes. Plate 11 shows the machine on which he made his journey cross-country from Etampes to Chevilly, a distance of 27 miles, and on that occasion he flew across a railway train, over one of the churches, and over various buildings.

On the 25th of July Blériot attempted to cross the British Channel and succeeded. Plate 12 is from a photograph taken on that occasion. That trip comprised a distance of 33 miles and was made in 37 minutes. It created great excitement, great applause, and great wonder, although, as a matter of fact, it was perhaps not as difficult a feat as the previous flying across country, but it appealed very much more to the imagination.

Blériot then went to the meeting at Rheims in Champagne, and there exhibited some very good performances. He flew over the grandstand at a very great height, made a trip on the 27th of August of 25 miles in 41 minutes, winning the ninth prize for distance, while on the succeeding day he flew 6 miles in 7 minutes and 48 seconds, winning the first prize for speed.[2]

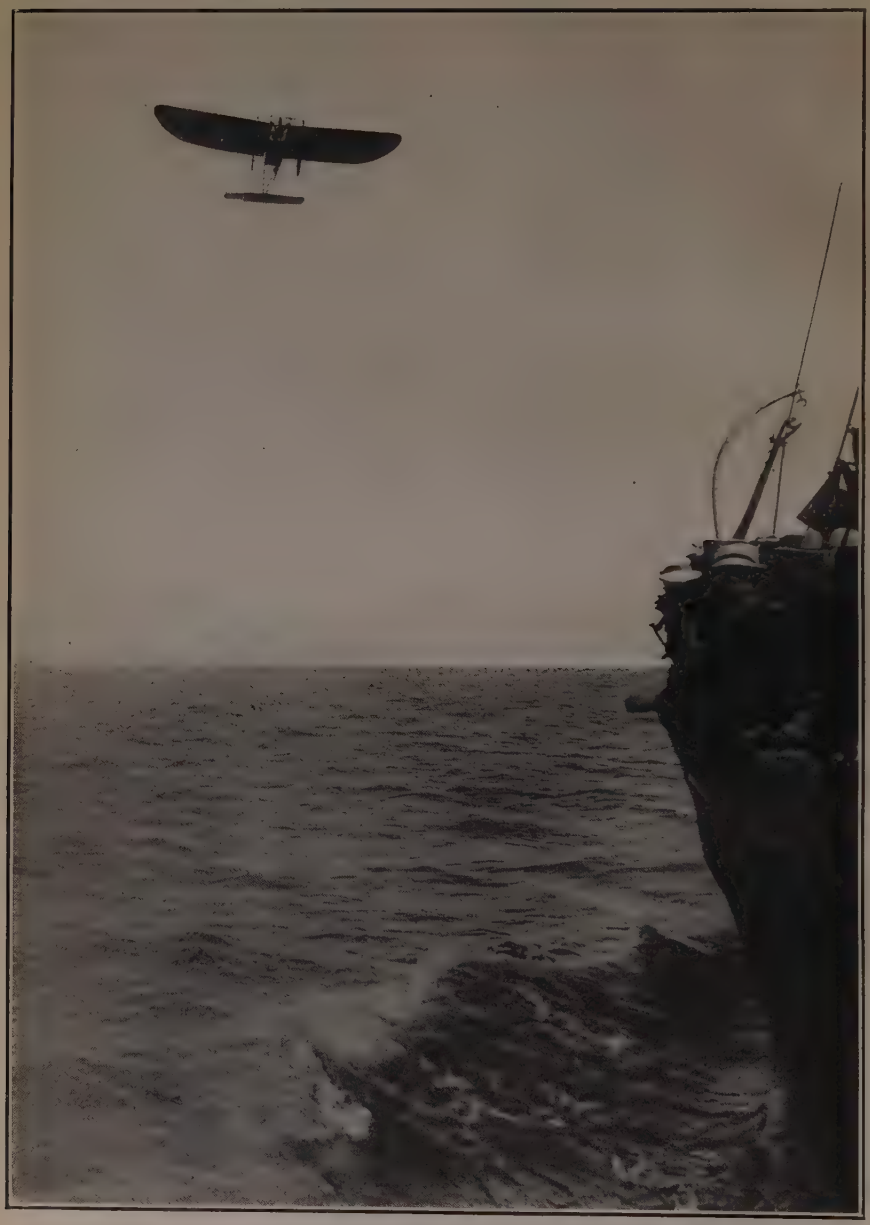
The next man who began experimenting was Mr. Esnault-Pelterie, a young French civil engineer, who started out with gliding machines, and then built a monoplane. Plate 8, figure 3, gives a view of the 1908 design. That is the machine as finally perfected. He has made quite a number of flights, but no very long ones nor any high ones, the highest being 100 feet.

Capt. Ferber, who is next to be mentioned, has been the chief apostle of aeroplanes in France. He became interested in the subject at an early date (1898) and has been promoting aeroplanes ever since. He began with gliding experiments. At first he was greatly in favor of the monoplane, but when I explained to him the advantages of

[1] See appendix for account of flights with Blériot machine No. 5, built on Langley type.

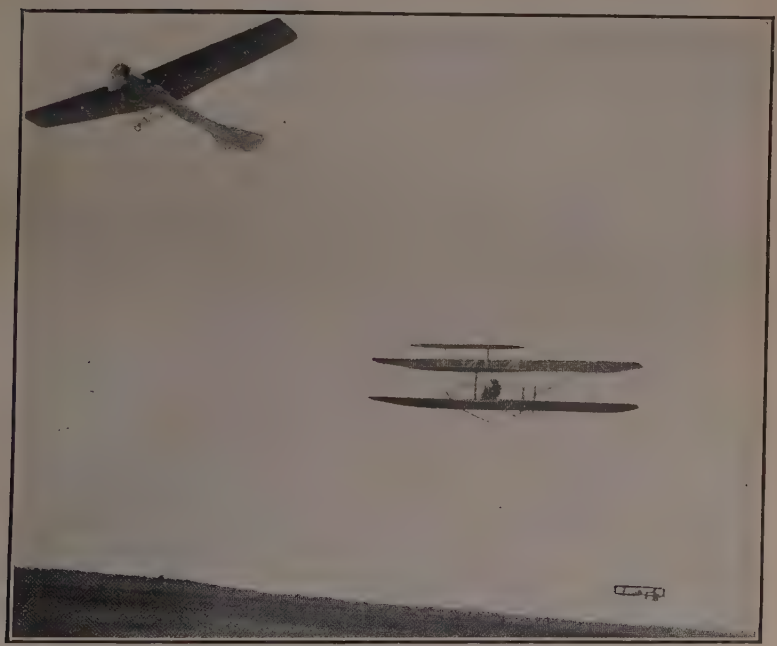
[2] Subsequently, Dec. 12, 1909, he was driven against a house during an exhibition flight at Constantinople, met with his twenty-second fall, and sustained injuries sufficiently severe, though not fatal, to require his going to a hospital.

BLÉRIOT'S MONOPLANE. ACROSS COUNTRY.



BLÉRIOT'S MONOPLANE. ACROSS CHANNEL.

1. FERBER'S BIPLANE IN FULL FLIGHT.



2. LATHAM (AT TOP), LEFEBVRE, AND BUNAU-VARILLA.

1. LATHAM'S ANTOINETTE MONOPLANE IN THE ENGLISH CHANNNEL AND THE RESCUE.

2. PAULHAN ON VOISIN MACHINE AT RHEIMS.

the biplane, he accepted that design, although he did not like the stiff, horizontal lines, and introduced bird-like transversal curves. Then he added a motor; this was applied to the No. 9 machine, in which he still had these transversal curves in the wings; he had the propeller in front, and instead of twisting the wings he used fins at the rear, which are adjustable. He obtained some very fair results. This machine is shown in plate 13, figure 1. On the 5th of September, 1909, he borrowed a Voisin machine and undertook a trial flight at Boulogne, preliminary to attempting to cross the British Channel, where it is about 40 miles wide, but, in making a turn, his machine tipped over unduly to the left. He undertook to alight, but in doing so his left wing struck a lump of earth, or hummock, when the wheels rolled into a ditch, the machine turned turtle, and poor Ferber was killed, to the profound sorrow of all interested in aviation. He is the third victim thus far this year,[1] but the wonder all along has been that so few accidents have occurred. There have been thousands of flights made—for instance, 1,300 were made in one week at the Rheims tournament—but thus far only three deaths have occurred.

More people kept coming into the field, and among the later ones is Mr. Hubert Latham, with a monoplane called the "Antoinette." Mr. Latham has risen to sudden prominence by some daring feats. Mr. Levavasseur designed and built this monoplane and engaged Mr. Latham to operate his machine. With it Mr. Latham got some very fine flights, such as that shown in plate 13, figure 2, taken at Rheims. On the 6th of June, 1909, he went across the country 10 miles from Juvisy. On the 19th of July he attempted to cross the British Channel, but was unsuccessful. On the 27th of July he tried it again, and flew 20 miles, or within 1 mile of Dover; the motor then gave out and he fell into the sea, the rescue being shown in plate 14, figure 1. On the 26th of August, at the meeting at Rheims, he flew 96 miles in 2 hours and 18 minutes, and won the second prize for distance. On that occasion he rose 508 feet, a record which has since been beaten by Paulhan and Rougier, who have developed an extraordinary aptitude for high flights. On his first attempt, on the 10th of July, 1909, Paulhan was able to fly 1.25 miles. On the 19th of July he flew 12 miles across country; on the 7th of August, 23 miles; on the 24th of August, 18 miles on a Voisin machine, and on the 25th of August he flew 81 miles at Rheims, winning third prize for distance. He has since made very fine flights in various meets. Plate 14, figure 2, is from a photograph taken at Juvisy.

The next man to reach prominence is Mr. Sommer. On the 4th of August, 1909, he flew 2 hours; on the 27th of August, 37 miles at Rheims; on the 10th of September, 18 miles over troops in review;

[1] Since then Aviator Fernandez was killed at Nice, Dec. 6, by a fall in his aeroplane.

on the 11th of September, 24 miles, from Nancy to Lenoncourt. Plate 15, figure 1, shows a flight in company with Farman.

E. Lefebvre, an automobile dealer, having purchased a Wright machine, laid down lines of rails and taught himself how to operate and fly the machine. At Rheims he made some very good performances. On the 27th of August he flew 12.5 miles in 20 minutes and 47 seconds. Unfortunately, upon the 7th of September, when testing a new Wright machine, he was upset and killed, this being the first fatal accident to occur in 1909.

One of the last men to come into prominence in France has been Mr. Henri Rougier, who operates a Voisin machine (pl. 15, fig. 2), and who has made some remarkable high flights. At Brescia he reached 328 feet of altitude, and later, on another occasion, 650 feet of altitude was reached. At Berlin he won the first prize for distance. On the 18th of October, at Blackpool meeting in England, he made a flight of 18 miles in 25 minutes, but all of those performances in height fall far short of the performances of Orville Wright, who rose to a height of 1,600 feet.

By the contract in which the Wright brothers agreed to sell their French patents to a syndicate, Mr. Wilbur Wright was to teach three pupils to operate the machines. The men selected were the Count de Lambert, Mr. Paul Tissandier, and Capt. Lucas-Girardville. The latter, being an army officer, has not appeared in any public tournament, but Mr. Tissandier has made many good flights, the longest up to the present time being one of 69 miles at Rheims, and he has been training pupils of his own. Count de Lambert made a flight of 72 miles at Rheims, and day before yesterday (Oct. 18) he made a sensational journey from the aviation grounds at Juvisy, where plate 16, figure 1, shows one of his flights over a portion of Paris to the Eiffel Tower and back, some 30 miles. This feat, as well as the flight of Latham on September 27 over the suburbs of Berlin, is disfavored by the Wrights as involving undue risks of accident.

Wilbur Wright also taught two pupils in Italy (where he sold a machine)—Lieut. Calderara, who flew at Rome and at Brescia, winning some prizes and meeting with accidents, and Lieut. Savoya, whose performances have not been made known.

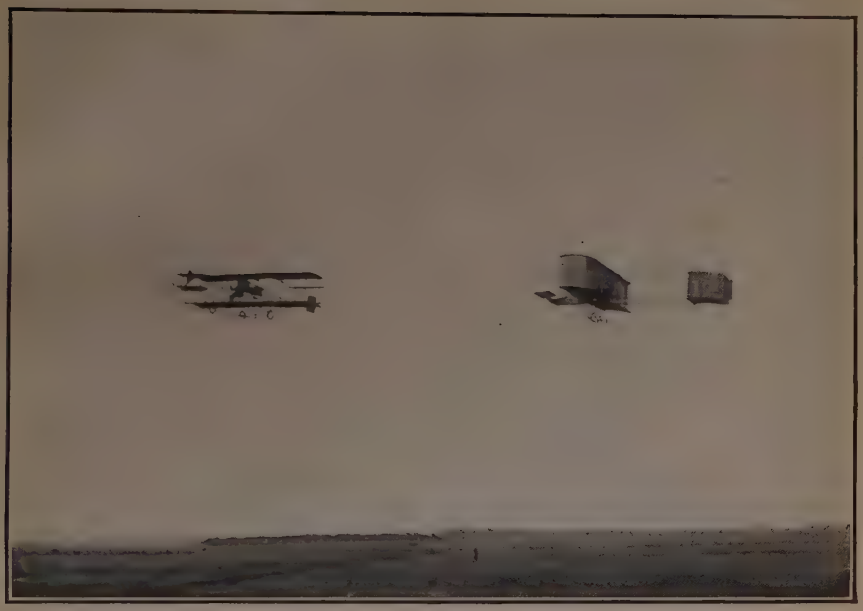
Mr. Legagneux and Mr. Bunau-Varilla also made creditable flights at Rheims upon machines built by Voisin Bros. (pl. 16, fig. 2), but the performances most commented upon at that tournament were those of Mr. Glen Curtiss, who, with a machine built by himself, won the Gordon Bennett cup by making the shortest time over 20 kilometers; won the first prize for speed in a flight of 30 kilometers (46 miles an hour), and the second prize for speed over 10 kilometers, in which he flew at 48 miles per hour. Plate 17 shows these

1. SOMMER AND FARMAN IN RACE.

2. ROUGIER'S VOISIN RISING FROM STARTING GROUND.

1. DE LAMBERT ON WRIGHT MACHINE.

2. BUNAU-VARILLA ON VOISIN BIPLANE.



1. CURTISS AND BUNAU-VARILLA.

2. THE "JUNE BUG" AT HAMMONDSPORT, N. Y.

1. BLÉRIOT AEROPLANE NO. 5 AFTER A FALL.

2. BLÉRIOT AEROPLANE NO. 5 AFTER FLIGHT OF 265 METERS, AUGUST 6, 1907, AT ISSY LES MOULINEAUX. (LANGLEY TYPE.)

flights. Subsequently Mr. Curtiss won the grand prize at the Brescia meet by flying 31 miles in 49 minutes and 24 seconds. He had previously won twice the Scientific American trophy in this country, once, July 4, 1908, by a flight of 5,090 feet at Hammondsport, N. Y., and again, July 24, 1909, by a flight of 25 miles in 52 minutes and 30 seconds.

This was the direct outcome of the labors of the Aerial Experiment Association, organized in 1908 by Alexander Graham Bell, upon the suggestion of Mrs. Bell, who generously contributed the funds. Dr. Bell had been experimenting with groupings of tetrahedral kites, which exhibited extraordinary steadiness in the air. He hoped to develop them into an efficient flying machine of automatic stability, and had been well served in his experiments by two young Canadian engineers, Mr. F. W. Baldwin and Mr. J. A. D. McCurdy. In order to give these faithful men a chance to test their own ideas the Aerial Experiment Association was organized by taking in (besides the three named) Lieut. Selfridge and Mr. Curtiss, the latter then being a manufacturer of motor cycles and motors at Hammondsport, N. Y., where the experiments were first started. The association built four flying machines—the *Red Wing*, the *White Wing*, the *June Bug*, and the *Silver Dart*—all of double-bowed shape, shown in plate 17, figure 2, and equipped with Curtiss motors. With these some very promising flights were made, both at Hammondsport and at Baddeck, Nova Scotia, to which the association removed and where Mr. McCurdy made flights of 16 miles and over.

I have memoranda of many more flights that have been made by other aviators, but I think they will be of less interest than the moving pictures about to be shown.

[Editor's Note: The talk was illustrated by many beautiful and interesting scenes, exhibited by the stereopticon, which are virtually, though not necessarily exactly, the engravings printed in this paper. At the close of the address, some beautiful and wonderful views of different machines in flight were shown by the aid of a moving-picture machine installed that evening for the purpose. The illustrations on plates 1, 4, 5; figs. 1 and 3 on pl. 8; fig. 1, pl. 10; fig. 1, pl. 14; and fig. 2, pl. 15 are from Victor Lougheed's "Vehicles of the Air," kindly loaned by the Reilly & Britton Co., publishers.]

Appendix I.

The following account of flights with the Blériot Machine No. 5 (the Langley type) referred to by Mr. Chanute on page 154 is translated from Bullettino della Società Aeronautica Italiana, August, 1907.

THE NEW BLÉRIOT AEROPLANE.

The Blériot IV, in the form of a bird, of which we spoke at length in No. 4 of the Bulletin of this year, does not appear to give good results, perhaps on account of its lack of stability, and Blériot, instead of trying some modifications which might remedy such a grave fault, laid it aside and at once began the construction of a new type, No. V, adopting purely and simply the arrangement of the American, Langley, which offers a good stability (see Bulletin 11-12, Nov. to Dec., 1905, pp. 187 and 188). The experiments, which were commenced a month ago, were first completely negative, because the 24-horsepower motor would not turn the propeller, which was 1.80 meters in diameter and 1.40 meters pitch. By advice of Capt. Ferber, Blériot reduced the pitch of his propeller to 0.90 meters, so that the motor could give all its force.

This modification was an important one for his aeroplane. From that moment every trial marked an advance. On July 12 he made a flight of 30 meters, and the aviator was able to show that the lateral stability was perfect. On July 15 the trial was made against a wind of 6 miles an hour, but gave good results. He made a flight of 80 meters, showing, however, that the hind part of the aeroplane was too heavy. In this flight he arose as high as a second story and on landing the wheels and one propeller were somewhat damaged.

On July 24, repairs having been completed, a new trial was made. This time, in order to remedy the defect in the balance, Blériot had moved his seat forward about 80 centimeters. The correction was too great, for on that day the aeroplane, although the hind part arose, was not able to leave the ground. On July 27, after having mounted the seat on wheels, as in skiffs, Blériot resumed the trials and made a flight of 120 meters, at first moving his seat back and then, after getting started, bringing it forward. Blériot had not provided this aeroplane with an elevating rudder, but, following the example of Lilienthal, changed the center of gravity of the apparatus by moving his own person, and after having established the proper angle remained immovable on his seat. In order to arise or descend the aviator made use of the spark lever, thus varying the number of turns of the propeller.

During a second trial on the same day, having accidentally reached the limit of the aviation field, Blériot, without allowing himself to be surprised and obliged to descend, decided to attempt a turn by maneuvering the steering rudder and to return again to the center of the field. With marvelous precision the aeroplane began to describe a circle of about 200 meters radius, inclining as if on a *pista cidistica*. Having finished the flight he quickly regained his balance, still in the direction of the wind, but on account of a slight movement of the aviator the aeroplane fell to such an extent that he was obliged to land. He landed gently and without shock, rolling on his wheels.

On August 1 he made another flight of 100 meters in 6½ seconds, and on the 6th one of 265 meters, with one interruption. While the attention of the pilot was distracted for a moment the aeroplane, which was flying at a height of 2 or 3 meters above the ground, touched the soil with its sustaining wheels at the end of 122 meters, and then, immediately arising, covered the remaining 143 meters at a height of 12 meters. Blériot, moving forward too quickly, caused the aeroplane to descend swiftly to the ground, and the shock broke the axle and the blades of the propeller were bent. In order to confirm this account we reproduce what was said in the Auto of August 7, 1907:

"M. Blériot, continuing the trials of his aeroplane yesterday, surpassed the superb results which he had already obtained. The trial took place at 2 o'clock in the afternoon on the aviation field of Issy. After a sustained flight of

1. BLÉRIOT AEROPLANE NO. 5. (LANGLEY TYPE.)

2. BLÉRIOT AEROPLANE NO. 5 IN FLIGHT. (LANGLEY TYPE.)

about 122 meters at a height of 2 meters, the aeroplane touched the ground, without stopping, however, and set out again almost immediately at a height of 12 meters and traversed about 143 meters. M. Blériot, who for the time had no other means of balancing but by moving his body, then moved a little forward to stop the ascent. The aeroplane plunged forward, and in the fall the propeller was damaged and the axle broken.

"M. Blériot, whose courage as a sportsman equals his learning as an engineer, was fortunately uninjured. An inspection of the apparatus showed that one blade of the propeller was bent, which was sufficient to prevent the maneuver made by the aviator having its desired effect and contributed to the fall. The engine will be repaired without difficulty and the trials will be resumed Friday."

On August 10 he made a flight of 80 meters, but the motor was not in perfect order, so Blériot did not make other trials. He decided, however, to substitute definitely a 50-horsepower motor for the 24-horsepower motor with which he made all the experiments above reported, which were of a character to encourage the most sanguine expectations.

Ferber advised Blériot to adopt an elevating rudder also, because the effect produced by changing the position of the center of gravity, although efficacious, is very difficult and delicate to control.

Appendix II.

The following table, compiled by the author, is here reprinted through the courtesy of the World Almanac, 1910:

CHRONOLOGY OF AVIATION.

[Compiled by O. Chanute.]

Bewildering advance in aviation took place in 1908 and 1909. When it is remembered that the first successful man flight, landing safely, was made by Wright brothers December 17, 1903, that it took them two years—1904–1905—to obtain entire control over their machine; that the Santos-Dumont flight of 720 feet, November 13, 1906, excited the wonder and admiration of all Europe, we can realize partially the progress made, now that flights of over 100 miles have been made, that a height of 1,600 feet is said to have been attained; that there are hundreds of successful experimenters in the field, and that records are being broken every few days.

It would be quite futile to give a compendium of all the flights made in 1909. They number thousands. The profitable thing which can be done is to tabulate the more remarkable performances; and, in order to mark the advance, to include therewith the former feats of the same aviator, which excited wonder only one or two years ago. The most interesting of these are prefixed with a star.

During 1909 exhibitions of aviating apparatus were held in Paris, December 24 to 30, 1908; in London, March 19 to 27; in London again, July 6 to August 4; in Frankfort, July 10 to October 10; in Paris again, September 25 to October 17; and these drew great crowds; while meets, contests, and tournaments were held at Rheims, August 22 to 29; at Brescia, September 5 to 20; at Berlin, September 26 to October 3; at New York, September 25 to October 2; at St. Louis, October 4 to 10; at Paris, October 2 to 21; and at Blackpool and at Doncaster, October 15 to 23.

The events which have attracted most attention have been the cross-country flight of H. Farman, from Bouy to Reims, 17 miles, without landing, October 30, 1908; of Bleriot, October 31, 1908, from Toury to Artenay and return, with landings; of the same man from Etampes to Chevilly, 26 miles, July 13, 1909, and his flight across the British Channel, July 25; the two unsuccessful attempts of Latham to perform the same feat, July 19 and July 27, 1909; the flight of Farman, July 23, from Chalons to Suippes, 40 miles; of his flights at Rheims of 112 miles, August 27, and of 150 miles at Mourmelon, November 3; of Orville Wright, at Fort Myer, July 27 and 30; of W. Wright, at New York, October 4; of Curtiss, at Rheims, August 28 and 29; of Latham, over Berlin, September 27; and of De Lambert, over Paris, October 18; as well as a speed of about 90 miles an hour, down wind, at Blackpool, attained by Latham, October 22, 1909.

These feats have not been accomplished without some deplorable accidents. Several aviators have been killed or injured by the fall of their machines, and many of the latter have been smashed. It will be remembered that Lieut. Selfridge was killed at Fort Meyer, September 17, 1908. In 1909 Eugene Lefebvre was killed at Juvissy, September 7; on the same day Enea Rossi was killed at Rome while testing a machine of his own invention; while on September 22 the distinguished propagandist of aviation in France, Capt. L. F. Ferber, was killed at Boulogne by an unlucky landing. On December 6, A. Fernandez, a French aviator of Spanish birth, was killed at Nice by the fall of his biplane, similar to Wright's, caused by the explosion of his motor when at a height estimated at 500 meters.

The tendency has been to develop special experts for exhibition flights. Some 200 of their flights, which are thought the more memorable for one reason or another, will be found in the following list:

Chronology of memorable flights—Motor Aeroplanes.

WILBUR WRIGHT.

Date.	Machine.	Place.	Distance.	Time.	Persons.	Remarks.
				H. m. s.		
Dec. 17, 1903[1]	Biplane	Kitty Hawk	852 feet	0 00 59	1	First successful man flight in history.
Nov. 9, 1904	do	Dayton, Ohio	3 miles	4 30	1	Made 105 flights that year.
Oct. 5, 1905	do	do	24 miles	38 00	1	Made 49 flights that year.
Aug. 8, 1908	do	Mans			1	Short flights showing control.
Sept. 21, 1908[1]	do	Auvours	41 miles	1 31 00	1	Made over 100 flights here.
Oct. 10, 1908	do	do	46 miles	1 9 00	2	With Mr. Painleve; took 35 others.
Dec. 18, 1908[1]	do	do	62 miles	1 54 00	1	Rose to 360 feet; then world record.
Dec. 31, 1908[1]	do	do	77 miles	2 20 23	1	Won Michelin prize; world record.
Mar. 20, 1909	do	Pau, France		6 00	1	No previous propulsion; teaches 3 pupils.
Apr. 16, 1909	do	Rome			2	Took up many passengers.
Apr. 26, 1909	do	do			1	No previous propulsion.
Sept. 25, 1909[1]	do	New York			1	Circled Statue of Liberty.
Oct. 4, 1909[1]	do	do	21 miles	33 33	1	To Grant's tomb and return.

Chronology of memorable flights—Motor Aeroplanes—Continued.

ORVILLE WRIGHT.

Date.	Machine.	Place.	Distance.	Time.	Persons.	Remarks.
				H. m. s.		
Sept. 8, 1908	Biplane	Fort Myer	40 miles	0 62 00	1	Unofficial; rose to 100 feet.
Sept. 12, 1908 [1]	do	do	50 miles	1 15 00	1	Longest flight of 1908.
Sept. 17, 1908 [1]	do	do	3 miles	4 00	2	Selfridge killed; Wright injured.
July 20, 1909	do	do		1 20 00	1	Unofficial test.
July 21, 1909	do	do		1 29 00	1	Do.
July 27, 1909 [1]	do	do		1 13 00	2	Official time test; machine accepted.
July 30, 1909 [1]	do	do	10 miles	14 00	2	Official speed test; 42 miles per hour.
Aug. 29, 1909	do	Berlin		15 00	1	Many preliminary exhibitions.
Sept. 4, 1909	do	do		55 00	1	
Sept. 8, 1909	do	do		17 00	2	With Capt. Hildebrandt.
Sept. 9, 1909	do	do		15 00	2	With Capt. Englehardt.
Sept. 17, 1909	do	do		54 26	1	In presence of Empress rose to 565 feet.
Sept. 18, 1909 [1]	do	do		1 35 47	2	With Capt. Englehardt.
Oct. 2, 1909	do	do		10 00	2	With Crown Prince of Germany.
Oct. 4, 1909 [1]	do	do	21 miles	33 33	1	Reached height of 1,600 feet; unofficial world record.

A. SANTOS DUMONT.

Nov. 13, 1906 [1]	Cellular	Bagatelle	720 feet	0 21 00	1	First flight in Europe.
Nov. 17, 1907	Biplane	Issy	500 feet		1	Made several flights.
Nov. 21, 1907	Monoplane	Bagatelle	400 feet		1	Do.
Mar. 10, 1909	do	do	1,300 feet		1	With the Libellule.
Apr. 10, 1909	do	St. Cyr	1.2 miles		1	With the Demoiselle.
June 19, 1909	do	Issy	820 feet		1	Several other flights.
Sept. 13, 1909 [1]	do	St. Cyr	5 miles	12 00	1	St. Cyr to Buc to visit friend.
Sept. 17, 1909 [1]	do	do	10 miles	16 00	1	Across country.

LEON DELAGRANGE.

Mar. 16, 1907	Biplane	Bagatelle	30 feet		1	First Voisin aeroplane.
Mar. 29, 1908 [1]	do	Ghent	453 feet		2	First flight with passenger (Farman).
Apr. 11, 1908	do	Issy	2.43 miles	0 6 30	1	Won Archdeacon cup.
May 27, 1908	do	Rome	7.90 miles	15 26	1	In presence of King, etc.
June 22, 1908	do	Milan	10.50 miles	16 30	1	Best flight on Italian trip.
July 8, 1908 [1]	do	Turin	500 feet		2	First woman passenger (Mrs. Peltier).
Sept 6, 1908	do	Issy	15.2 miles	29 53	1	Beat then existing records.
May 23, 1909	do	Juvissy	3.6 miles	10 18	1	Won Lagatineri prize.
June 12, 1909	do	do	3.7 miles		1	Circling across country.
Aug. 23, 1909	Monoplane	Rheims		11 4	1	Won tenth prize; speed.
Aug. 27, 1909	do	do	31 miles		1	Won eighth prize; distance.
Sept. 15, 1909	do	Denmark		15 00	1	Before King, at Aarhus.
Oct. 16, 1909	do	Doncaster	5.75 miles	11 25	1	To keep crowd from grumbling.
Oct. 26, 1909 [1]	do	do	6 miles	7 36	1	Over 50 miles an hour.

Chronology of memorable flights—Motor Aeroplanes—Continued.

HENRY FARMAN.

Date.	Machine.	Place.	Distance.	Time.	Persons.	Remarks.
				H. m. s.		
Oct. 26, 1907	Biplane	Issy	253 feet		1	First sweeps a half circle.
May 30, 1908	do	Ghent	0.77 miles		2	With Mr. Archdeacon.
July 6, 1908	do	do	12.2 miles	0 19 3	1	Won Armengaud prize.
Oct. 30, 1908[1]	do	Chalons	17 miles	20 00	1	Cross-country, Chalons to Rheims.
Oct. 31, 1908	do	do		23 00	1	82 feet altitude; won prizes.
July 18, 1909	do	do		1 23 00	1	His first long flight.
July 23, 1909[1]	do	do	40 miles	1 5 00	1	Cross-country, Chalons to Suippe.
Aug. 27, 1909[1]	do	Rheims	112 miles	3 4 57	1	First prize for distance and time up.
Do	do	do	6 miles	10 00	3	With 2 passengers; won prize.
Oct. 3, 1909[1]	do	Berlin	62 miles	1 40 00	1	Won third prize, $960.
Oct. 18, 1909	do	Blackpool	14 miles	23 00	1	On first day of meeting.
Oct. 20, 1909[1]	do	do	47 miles	1 32 16	1	Won prize of $10,000.
Nov. 3, 1909[1]	do	Mourmelon	137.25 miles	4 6 25	1	Said to be 150 miles; 4 hours 17 minutes 35 seconds.

LOUIS BLÉRIOT.

Aug. 6, 1907	Langley	Issy	470 feet		1	His first attempt to circle.
July 4, 1908	Monoplane	do	3.7 miles	0 5 47	1	Swept several circles.
Oct. 21, 1908	do	Toury	4.25 miles	6 40	1	At height of 65 feet
Oct. 31, 1908	do	do	8.7 miles	11 00	1	Toury to Artenay, landed.
Do	do	do	do		1	Artenay to Toury; intermediate landing.
May 30, 1909	do	Issy	do		1	Over adjoining fields.
June 12, 1909[1]	do	Juvissy	984 feet		3	Santos Dumont and Fournier as passengers.
July 13, 1909[1]	do	Mondesir	26 miles	44 30	1	Etampes to Chevilly, cross-country.
July 25, 1909[1]	do	Calais	32 miles	37 00	1	First flight across British Channel.
Aug. 28, 1909[1]	do	Rheims	6.3 miles	7 48	1	Won first prize speed for 6-mile trip.
Aug. 27, 1909	do	do	25 miles	41 00	1	Won ninth prize for distance flown.

S. F. CODY.

Feb. 22, 1909	Biplane	Aldershot	1,200 feet		1	In a 12-mile wind.
May 14, 1909	do	do	1 mile		1	On the Army biplane.
July 21, 1909	do	do	4 miles		1	On rebuilt machine.
Aug. 29, 1909	do	do	10 miles		2	With passenger in three flights.
Sept. 8, 1909[1]	do	do	40 miles	1 3 00	1	Circuit to Farnborough and return.
Sept. 11, 1909	do	do			1	Before Empress Eugenie.
Oct. 16, 1909	do	Doncaster	3,000 feet		1	Machine wrecked; aviator hurt.

Chronology of memorable flights—Motor Aeroplanes—Continued.

MOORE-BRABAZON.

Date.	Machine.	Place.	Distance.	Time.	Persons.	Remarks.
				H. m. s.		
Jan. 28, 1909	Biplane	Chalons	3.1 miles		1	Learning use of Voisin machine.
Feb. 24, 1909	do	Issy	1.2 miles		1	Swept over two circles.
Feb. 28, 1909	do	do	2.5 miles		1	Several flights.
Apr. 30, 1909	do	England	4.5 miles		1	Gradually improves performances.
Oct. 30, 1909	do	Shell Beach			1	Won Daily Mail $5,000 prize for flight with a British machine.

L. F. FERBER.

Aug. 8, 1908	Biplane	Issy			1	First trials with motor machine.
Sept. 19, 1908	do	do	1,640 feet		1	His aeroplane No. 9.
June 13, 1909	do	Juvissy	3.1 miles	0 5 30	1	On a Voisin machine.
Sept. 15, 1909[1]	do	Boulogne	6 miles	9 00	1	Boulogne to Wimeroux.
Sept. 22, 1909	do	do	1 mile		1	Landed in ditch; killed.

ESNAULT PELTERIE.

Oct. 19, 1907	Monoplane	Buc				First short flights.
June 8, 1908	do	do	0.75 mile		1	At height of 100 feet.

HUBERT LATHAM.

May 19, 1909	Monoplane	Chalons	1,640 feet		1	Begins operating the Antoinette.
June 5, 1909	do	do		1 7 37	1	In wind and rain; breaks record.
June 6, 1909	do	Juvisy	10 miles		1	Cross-country flight.
June 12, 1909	do	do	30 miles	39 00	1	Won Goupy prize.
July 19, 1909[1]	do	Calais	11 miles		1	Over British Channel; fell in sea.
July 27, 1909[1]	do	do	20 miles		1	British Channel; fell near Dover.
Aug. 26, 1909[1]	do	Rheims	96 miles	2 18 9	1	Won second prize for distance.
Aug. 27, 1909[1]	do	do			1	Won first prize; altitude, 508 feet.
Sept. 27, 1909[1]	do	Berlin	6.5 miles	13 00	1	Across suburbs of Berlin.
Sept. 29, 1909	do	do	42 miles	1 10 00	1	Won second prize for distance.
Sept 30, 1909	do	do	51 miles	1 23 00	1	Machine broken in landing.
Oct. 22, 1909[1]	do	Blackpool			1	Flew in gale; won prize, $1,500.
Nov. 19, 1909	do	Chalons		10 00	1	Rose 1,345 feet, competing, Weiler prize.
Dec. 1, 1909	do	Mourmelon			1	Rose 1,500 feet in 40-mile wind.

Chronology of memorable flights—Motor Aeroplanes—Continued.

LOUIS PAULHAN.

Date.	Machine.	Place.	Distance.	Time.	Persons.	Remarks.
				H. m. s.		
July 10, 1909[1]	Biplane	Douai	1.25 miles		1	His very first flight.
July 15, 1909	do	do		1 17 00	1	Reached altitude of 357 feet.
July 19, 1909[1]	do	do	12.1 miles	22 53	1	Cross-country, Douai to Arras.
July 23, 1909	do	do	43.5 miles	1 17 19	1	Official allowance, 30 miles.
Aug. 6, 1909	do	Dunkerque		18 20	1	Altitude, 200 feet.
Aug. 7, 1909	do	do	23 miles	33 00	1	On a Voisin biplane.
Aug. 24, 1909	do	Rheims	18.6 miles	38 12	1	Altitude, 295 feet.
Aug. 25, 1909[1]	do	do	81 miles	2 43 24	1	Won third prize for distance.
Sept. 9, 1909	do	Tournai	12.4 miles	17 00	1	Two cross-country flights.
Sept. 13, 1909[1]	do	do		1 35 00	1	Tournai to Taintignies and return.
Sept. 17, 1909	do	Ostend	1.24 miles	3 16	1	Circled over sea.
Sept. 18, 1909	do	do		1 1 1	1	Over sea front; won $5,000 prize.
Oct. 10, 1909	do	Port Aviation	21.5 miles	21 48	1	Flew over line of the stands.
Oct. 12, 1909	do	do	3.6 miles	6 11	1	Won prize for slowest flight, $600.
Oct. 18, 1909	do	Blackpool	14 miles	25 53	1	On first day of Blackpool meeting.
Oct. 19, 1909[1]	do	do	15.75 miles	32 18	1	Won third prize for distance, $1,400.
Nov. 19, 1909	do	Chalons			1	Rose 1,210 feet, competing, Weiler prize.
Nov. 20, 1909[1]	do	Mourmelon	37 miles	55 00	1	Chalons and return. Rose nearly 1,000 feet.

ROGER SOMMER.

July 4, 1909	Biplane	Chalons	3.75 miles		1	On Farman's new machine.
July 18, 1909	do	do		1 4 00	1	Longest of several flights.
July 27, 1909[1]	do	do	25 miles	1 23 30	1	To Vadenay and back.
Aug. 1, 1909	do	do		1 50 30	1	Beats all French records.
Aug. 2, 1909[1]	do	do	9 miles	12 00	1	To Suippes; 45 miles an hour.
Aug. 4, 1909	do	do		2 0 10	1	Trying to beat Wright's record.
Aug. 7, 1909[1]	do	do		2 27 15	1	Beats Wright's record of Dec. 31, 1908.
Aug. 22, 1909	do	Rheims		1 19 33	1	On first day of Reims tournament.
Aug. 27, 1909	do	do	37 miles		1	Won seventh prize for distance.
Sept. 6, 1909	do	Nancy	25 miles	35 00	1	Also made flights with passengers.
Sept. 10, 1909	do	do	18 miles		1	Accompanies troops on review.
Sept. 11, 1909	do	do	24 miles		1	Nancy to Lenoncourt.
Oct. 16, 1909	do	Doncaster	9.7 miles	21 45	1	Best flight in Great Britain to date.
Oct. 26, 1909[1]	do	do	29.7 miles	44 53	1	Won Whitworth cup.

Chronology of memorable flights—Motor Aeroplanes—Continued.

M. ELLEHAMMER.

Date.	Machine.	Place.	Distance.	Time.	Persons.	Remarks.
				H.m.s.		
1906–1909	Biplane	Denmark			1	Experience with varied success.

ALEXANDER GRAHAM BELL.

1907–1909		Baddeck				Experiments; tetrahedral machine.

COUNT DE LAMBERT.

Mar. 17, 1909	Biplane	Pau		0 3 00	1	First flight alone; Wright's pupil.
Mar. 24, 1909	do	do	15.6 miles	27 11	1	Wins Aero Club prize for 250 meters.
Mar. 27, 1909	do	do		7 56	1	Flies beyond experimental field.
Apr. 13, 1909	do	do		1 30	2	With Delagrange as passenger.
Aug. 26, 1909[1]	do	Rheims	72 miles	1 52 00	1	Won fourth prize; distance.
Oct. 18, 1909[1]	do	Juvissy	31 miles	49 39	1	To Eiffel Tower and back across Paris.
Oct. 21, 1909	do	Port Aviation	1.25 miles	1 57	1	Wins $3,000 prize for speed.

PAUL TISSANDIER.

May 20, 1909	Biplane	Pau	35.7 miles		1	Pupil of W. Wright.
Aug. 22, 1909	do	Rheims	18.6 miles	0 29 00	1	Won third prize for speed over 30 kilometers.
Aug. 27, 1909[1]	do	do	69 miles	1 46 32	1	Won sixth prize for distance flown.

E. LEFEBVRE.

July 21, 1909	Biplane	La Haye	2 miles		1	Self taught on Wright machine.
Aug. 27, 1909[1]	do	Rheims	12.4 miles	0 20 47	1	Shows great boldness and skill.
Aug. 28, 1909	do	do		11 5	2	Performs evolutions with passenger.
Sept. 7, 1909	do	Juvissy	1,800 feet		1	Upset and killed.

MARIO CALDERARA.

April 28, 1909	Biplane	Rome		0 10 00	1	Pupil of W. Wright.
May 6, 1909	do	do			1	Upset and hurt.
Sept. 12, 1909	do	Brescia	6.3 miles		2	One passenger; won prize.
Sept. 15, 1909[1]	do	do	5.6 miles		2	Won Oldofredl prize.
Sept. 20, 1909[1]	do	do	31 miles	50 51	1	Won second prize for speed.

Chronology of memorable flights—Motor Aeroplanes—Continued.

GLEN H. CURTISS.

Date.	Machine.	Place.	Distance.	Time.	Persons.	Remarks.
				H. m. s.		
July 4, 1908[1]	Biplane	Hammondsport	5,090 feet	0 1 42	1	Wins Scientific American cup.
July 13, 1909	do	Mineola	1.5 miles	3 00	1	Tuning up Aeronautic Society machine.
July 17, 1909	do	do	15 miles	21 00	1	Described figure 8.
July 18, 1909	do	do	30 miles	52 30	1	Official distance, 25 miles.
July 24, 1909[1]	do	do	25 miles	52 30	1	Second winning Scientific American cup.
Aug. 24, 1909	do	Rheims	6.2 miles	8 35	1	Wins second prize; speed over 10 kilometers.
Aug. 25, 1909	do	do	6.2 miles	8 11	1	Bleriot is 7 seconds faster.
Aug. 26, 1909	do	do	19 miles	29 00	1	Wins tenth prize; distance and speed.
Aug. 28, 1909[1]	do	do	12.4 miles	15 56	1	Wins Gordon Bennett cup.
Aug. 29, 1909[1]	do	do	18.6 miles	23 30	1	Wins first prize, speed over 30 kilometers.
Do	do	do	6.2 miles	7 51	1	Wins second prize, speed over 10 kilometers.
Sept. 11, 1909	do	Brescia	31 miles	49 24	1	Wins first prize for speed.
Sept. 29, 1909	do	New York			1	Flights about Governors Island.
Oct. 10, 1909	do	St. Louis			1	Flights at Centennial celebration.
Oct. 16, 1909	do	Chicago	1 mile	1 30	1	Exhibition flights.

J. A. D. McCURDY.

May 18, 1908	Biplane	Hammondsport	600 feet		1	With the White Wing.
July 4, 1908	do	do	3,420 feet		1	With the June Bug.
Feb. 23, 1909	do	Baddeck	2,640 feet		1	With the Silver Dart.
Feb. 24, 1909	do	do	4.5 miles		1	Do.
Mar. 11, 1909	do	do	19 miles	0 22 00	1	Do.
Mar. 18, 1909	do	do	16 miles		1	Aggregate of 1,000 miles.
Aug. 2, 1909		Petawawa	20 miles		1	Many flights; broke machine.

LE BLON.

Oct. 18, 1909	Monoplane	Doncaster	22 miles	0 30 00	1	On Bradford cup; flew in rain.
Oct. 19, 1909	do	do	15 miles		1	Astonishing flight in a gale.
Oct. 20, 1909	do	do			1	Foolhardy flight in great gale.

F. W. BALDWIN.

Mar. 12, 1908	Biplane	Hammondsport	319 feet		1	With the Red Wing.
May 18, 1908	do	do			1	With the White Wing.
Mar. 18, 1909	do	Baddeck			1	With the Silver Dart.
Aug. 2, 1909	do	Petawawa			1	Several short flights.

Chronology of memorable flights—Motor Acroplanes—Continued.

LEGAGNEUX.

Date.	Machine.	Place.	Distance.	Time.	Persons.	Remarks.
				H. m. s.		
Feb. 14, 1909	Biplane	Mourmelon	1.2 miles		1	Pupil of Ferber.
Do	do	do	6.2 miles		1	Sweeps two circles.
Apr. 27, 1909	do	Vienna	2.5 miles	0 3 26	1	On a Voisin machine.
Aug. 6, 1909	do	Stockholm	3,280 feet		2	With a passenger.
Aug. 22, 1909	do	Rheims	6 miles	9 56	1	Won eighth prize for speed over 6 miles.

HENRI ROUGIER.

May 23, 1909	Biplane	Juvissy	18.6 miles		1	Swept eleven circles.
Aug. 29, 1909	do	Rheims			1	Won fourth prize; altitude 180 feet.
Sept. 9, 1909	do	Brescia		0 12 10	1	Reached 328 feet altitude.
Sept. 12, 1909[1]	do	do	31 miles	1 10 18	1	Reached 380 feet altitude.
Sept. 20, 1909[1]	do	do			1	Reached 650 feet altitude.
Sept. 28, 1909[1]	do	Berlin	31 miles	54 00	1	Rises to 518 feet.
Sept. 29, 1909	do	do	48 miles	1 35 00	1	In competition with Latham.
Oct. 1, 1909[1]	do	do	80 miles	2 38 00	1	Wins first prize, distance.
Oct. 18, 1909	do	Blackpool	17.7 miles	24 43	1	Wins second prize, $3,600.

E. BUNAU-VARILLA.

Aug. 5, 1909	Biplane	Chalons		0 15 00	1	Voisin biplane presented by father.
Aug. 22, 1909	do	Rheims	6.2 miles	13 30	1	Thirteenth prize for speed for 10 kilometers.
Aug. 29, 1909	do	do	18.6 miles	38 31	1	Eighth prize for speed for 30 kilos.

[1] Considered the most interesting flights on record.

PROGRESS IN RECLAMATION OF ARID LANDS IN THE WESTERN UNITED STATES.[1]

[With 12 plates.]

By F. H. Newell, *Director of Reclamation Service.*

PRESENT CONDITIONS.

The progress being made by the United States Government in the reclamation of arid lands under the terms of the so-called Reclamation or Newlands Act of June 17, 1902, has been notable, and the results as accomplished are instructive to students of engineering and economics. The plans and hopes have been touched upon in previous discussions, but the time has now arrived when more tangible conclusions are becoming available. The work is in an instructive stage in that it is possible to observe the results of the practical application of ideals of conservation and the working out of these in communities of considerable size.

Reclamation works have been laid out in all of the Western States and Territories and an investment of over $60,000,000 has been made. Part of the works in each State has been completed and is being operated, returning a part of the cost. About 10,000 families are being supplied with water. Most of these have come from the humid regions and have located upon tracts of land which formerly were considered valueless, and in portions of the country which were called desert. In short, by the use of a trust fund which is being returned and used over again, the waste waters of the Nation are being conserved, destructive floods prevented, apparently valueless land converted into highly productive farms, and thousands of families settled upon small tracts sufficient for their support. To this extent relief is being given to the tendency toward congestion in the industrial centers and home markets are being extended. The farmer located upon a small irrigated tract owned and cultivated by himself necessarily practices intensive farming, produces the highest

[1] This article is in continuation of papers printed in the Smithsonian Reports for 1901, pp. 407 to 423; 1903, pp. 827 to 841; 1904, pp. 373 to 381; 1907, pp. 331 to 345.

crop value per acre, is a large consumer as well as producer, and becomes the most valuable citizen in the stability of the commonwealth.

The individual projects are located far apart and the engineering problems connected with them are varied and many of them novel and difficult. They have not been confined to any one branch of engineering, but include not merely the ordinary surveying and practice of civil engineering, with planning and construction, but reach out into hydraulics, to electrical development and transmission of power and the use of the power in pumping water and incidentally in commercial enterprises, the manufacture of cement, and of various structures, large and small, together with the safe and economical handling of explosives, the digging and maintaining of tunnels, and innumerable mechanical operations.

Joined with the engineering has been the business side. This involves not merely the expenditure of the trust fund and the getting of the largest possible return for it, but also the careful accounting for all expenditures in terms of value received. It has not been the custom for work under Government auspices to be measured in the ordinary commercial way by returns. On the contrary, it has been usual to state simply that so much money has been appropriated and spent. Thus data are lacking for comparison of relative efficiency under Government and under corporate enterprise in most comparable operations, but in the use of the reclamation fund this side of the work has been made prominent.

The engineering and business problems have been met and successfully solved. The most difficult undertaking, however, is that incident to the stage of progress now being entered upon, namely, the operating side which involves successful dealing with the human as opposed to the physical elements. This means the tactful handling of thousands of individuals, collecting from them in small payments the original cost of the works, they in turn deriving this money from the sale of products of the soil, and at the same time operating the works in such way that the best results in crop production may be attained, also maintaining the structures so that ultimately, after having been paid for, they may be turned over to the landowners in the best possible condition.

The object of the reclamation act, as stated in the law is the construction of irrigation works for the reclamation of arid or semi-arid lands in the States and Territories named in the act. But the purpose behind the mere reclamation of the land is the providing of opportunities for homes for an independent self-supporting citizenship. The law is not drawn for the purpose of making men rich, but for providing opportunities for citizens who have the skill, energy, and thrift sufficient to make use of the opportunities for se-

curing a home for themselves and for their children; one in which the family may be supported; and one where with the growth of the country and increased land values, it will be possible for an increasing number of families to maintain themselves upon subdivisions of the original farms.

Thus far the wisdom of the framers of the act has been demonstrated, and it has been shown that, with wise administration, the law is proving of inestimable value to the States and to the Nation. From time to time, it is necessary to make improvements or changes in the organic law, such as are inseparable with growth, but as a whole this act has proved remarkably complete.

CHARACTER OF SETTLERS.

The character of the citizens who have taken up lands on these projects under terms of the homestead act, or have purchased them from the original occupants, is as varied as can well be imagined. Characterizing them as a whole, it may be said that they include the more energetic and venturesome part of the population, such as largely make up all pioneer communities; men who have the desire for the novelty and for change deeply planted in their character, who are wearied of the monotony of the old familiar life, and are attracted by the remote and unknown. Among them are many mechanics, shopkeepers, and clerks, who have had a longing to get into the open air, and who through energy and self-denial have saved a little money. Others are young farmers who can not find land near the old home and who wish to try their fortunes in the West. Others who come from nearer irrigated States, where the price of land has increased rapidly, and by selling the old farm for a high price they can obtain land equally as good at far less cost.

The would-be irrigators come from every part of the civilized earth but are mainly Americans. There are some men of the Latin races, Spanish and Italians, also Germans and the northern races, English, and Irish, a mingling of the white men of every variety of religious belief and of political affiliations.

As might be imagined, the population in the first few years is largely transitional. The same qualities which bring a man to a project tend to make him leave it. He has heard of all the good things, has read the roseate descriptions of irrigation, its benefits, but the drawbacks have never been brought to his attention. It is hardly to be wondered that many of the people who take up irrigation for the first time suddenly awake to the fact that it is not wholly a matter of sunshine and flowers, and that for success energy, skill, and thrift are required. In order to get well started on an irrigated

farm a man must have not only good fortune but must be prepared to endure privations which he would not be willing to consider at home; doing this, however, with the assurance that the reward ultimately will be correspondingly great.

This awakening to the fact that irrigation has its thorny side sometimes comes as a startling shock, sufficient to discourage all but the most enthusiastic or persistent, and the more faint hearted seek still farther for the promised land. Those who remain soon learn that success must be preceded by subduing the soil, getting it into a good condition of tilth, supplying the necessary nitrates and perhaps the phosphates, applying water day or night, and perhaps all night, wading around in the mud, or enduring the heat of the long days of brilliant sunshine and the accompanying dust of the arid regions, the troubles with neighbors over division of water, the possible seepage followed by crop losses, or ruin from alkali. All of these look very large at first to the man who has never given them thought, but they gradually fade again as time goes on and experience is attained.

As a consequence of these conditions a considerable part of the first settlers on every irrigation system sell out or relinquish their homesteads and seek other fields.

The second comer is more apt to stay. He has usually looked over the field in advance with considerable care and has weighed the disadvantages more carefully than his predecessor, but sometimes he in turn sells to a third comer, who may be regarded as the final locator.

The first and sometimes the second man has reaped more or less of a reward for the discomforts of pioneering. He has obtained the land for nothing or at very small cost, has, it is true, endured privations for a time, but has received an otherwise unearned increment in land values, due to construction of the works by the investment of capital not his own. Thus, if his land has cost him directly or indirectly $1 or $2 an acre, he usually sells it for $20 or $30 an acre, the final purchaser paying a reasonable amount for the land, but nearly what it is worth. The purchaser approaches the undertaking on the basis of a thorough appreciation of values and possibilities involved. He has not rushed in as have many of the pioneers because of the feeling that he was getting something for nothing, but on the contrary has carefully weighed the advantages and disadvantages and has paid a fair price with the knowledge that he must get his money back out of the land itself. With him it has not been a vision of comfort or luxury, but a realization of hard work involving certain risks, though with reasonable assurances of success.

SIZE OF FARM.

The size of the farms obtainable from the public domain is defined by the reclamation act not by an arbitrary number of acres, as in the case of the homestead and other similar laws, but the Secretary of the Interior is required to give a "limit of area per entry, which limit shall represent the acreage which in the opinion of the Secretary may be reasonably required for the support of a family upon the lands in question."

With reference to the right to the use of water sold for lands in private ownership, the limit is placed at 160 acres "to any one landowner, and no such sale shall be made to any landowner unless he be an actual bona fide resident on such land or occupant thereof, residing in the neighborhood." These provisions necessitate a study in advance of the character of the irrigable land, so that it may be divided into tracts in accordance with its quality, each of these farm units being of a size reasonably required when irrigated and cultivated for the support of a family.

In the extreme southern part of the arid region, where the daily sunlight and warmth is most favorable for the production of crops, it results that where the land is carefully tilled, where it has been put into high-grade crops, and especially in fruit, 10 acres may be ample for the support of a family. This is because of the fact that with intensive cultivation, crop follows crop in rapid succession, there being hardly any interval for rest during the year. Alfalfa, for example, may be cut eight or ten times, while there may be three successive crops during the year of grains or vegetables.

Farther north, where the summer season is limited, and there is a long cold winter, the area required for a family is correspondingly greater. With alfalfa and sugar beets, 40 acres may be considered a fairly good sized farm, as, for example, in the more favorable parts of Montana, and elsewhere, 80 acres is usually the limit. Few men can handle successfully over 80 acres of irrigated land, especially with high-priced water.

In laying out the farm units it is necessary to follow the conventional rectangular system adopted by the Government, of which the section, or 1 square mile, of 640 acres is the unit, and the quarter section of 160 acres is the size of the homestead entry. The smallest subdivision ordinarily recognized is the quarter-quarter section, or 40-acre tract, commonly known as a "forty." This in turn in the irrigated regions is again divided into quarter-quarter-quarters, or 10-acre tracts, this smaller subdivision not being generally recognized in the Land Office tracts.

Not all of any quarter section or even of the "forty" is usually irrigable. Generally the farm unit consists of, say, 80 acres in all,

of which 43 or 52 acres or some other number may be irrigable. The charge for water is apportioned according to the number of irrigable acres, irrespective of the total of the farm unit. This farm may extend across the canal to an extreme size of 160 acres, of which a portion may be dry land above the reach of water and a portion irrigable.

REQUIREMENT OF SETTLEMENT.

The requirement of actual settlement on the reclaimed land has been one which has led to much discussion and has been the cause of much of the hardship incident to pioneering. The theory of the law as originally passed was that the Government, investing this trust fund without profit and interest, does this for the purpose of securing settlement in the more sparsely populated western States. The prime object was not so much to enrich these localities or States as to secure resident citizens, who would not only cultivate the soil and become producers but would build up the institutions of the State, make roads, organize schools, and add to the strength of the Commonwealth.

If, however, the Government were to reclaim the lands and permit men living in near-by cities, or even in Chicago or New York, to purchase or hold these lands, cultivating them through tenants, the main object of the bill would be defeated. It would amount practically to lending this money without profit or interest to a favored few. Assuming, for example, that the proportional cost of reclaiming a 40-acre farm was $30 an acre, this would be $1,200 invested by the Government for the benefit of some one family. This $1,200 is to be repaid in 10 annual installments by the landowner. If he prefers to live in the city, and rents the use of the land to some other individual, this renter will have little or no interest in the permanent improvement and in development of the land and of the community. If either man is to be benefited by this loan of the Government, it should be the renter on the farm rather than the big or little capitalist living in town.

For this reason the resident clause has been held to be vital to the object of the act, although it has caused much hardship through the requirement that men bring their families out into the desert and live there throughout the early years of preparation. From the standpoint of a man working in a store or machine shop, a teacher or professional man, the idea is extremely attractive of getting one of these homesteads from the Government, visiting it occasionally, adding improvements, and hiring a man to look after it until the community has been built up and the days of pioneering have passed. His monthly savings can be put into the little farm and provision made for the future without interfering with his daily wage-earning

capacity. It seems to him a useless hardship to be compelled either to give up the farm or to go and live upon it, and he urges that if he be allowed to hold the farm and invest his savings in it he can in the end bring about a higher development than would be possible if he spent all his time on the farm itself.

There is, however, no way of distinguishing between the small investor and the large, and if the school-teacher has the right to enjoy absentee landlordism, so has the man of larger means. Thus it would soon happen that the bounty of the Government would be enjoyed by people of comparative wealth and leisure, renting their farms to the class of men who are most needed as resident owners.

CROPS.

The crops planted by the settlers are as varied as are the farmers themselves and the climatic surroundings. They naturally endeavor to raise the things with which they are familiar and are somewhat slow in adapting their methods to the requirements of the soil and climate. As a rule, grain is planted first, as it is a quick crop and it is possible to realize an early return from the new ground. The experienced irrigator endeavors to get a small part of the land into alfalfa as quickly as possible, knowing that it enriches the soil. With his first grain crop he sows on part of his land some alfalfa seed and if the stand is good he leaves this small tract in alfalfa for a few years, cultivating the remaining areas and adding each year to the alfalfa tract until the time arrives when he can plow in the alfalfa which was first planted, turning the plants under to enrich the soil, then cultivating it and planting to root crops (pl. 6, fig. 2).

One of the problems with the lighter and sometimes better soils is to hold these in place until the crops are established. The desert vegetation, the sagebrush and greasewood, while undisturbed protect the soil from the winds, but, as has been shown by bitter experience again and again, when these plants are removed and the ground is plowed the winds of early spring sweeping furiously across the dry level field blow the soil away in clouds, carrying off the seed (pl. 1, fig. 1).

It requires a few incidents of this kind to convince the newcomer that it is wise to follow the advice given him not to clear his entire farm at once, but to leave rows of sagebrush across the path of the prevailing spring winds. He soon appreciates that it is little short of wicked to burn the sagebrush, and instead of piling it for destruction he learns to leave it in long windrows, cultivating the places between until the ground is well shaded by the growing crop and the roots have been firmly established, then he can remove the remaining sagebrush or windbreaks and get his entire field into crop. In a few years,

by careful handling, the light soil becomes reasonably compacted, or held back by the roots and straw of the vegetation, or protected by the growing trees and shrubbery, so that no further damage is incurred.

PROBLEMS.

These problems of dealing with the settlers, of giving them sound advice, and at the same time collecting from them the cost of the works, involve the problems which are far more difficult than those of engineering construction or related business management. The difficulties of management are complicated by the fact that the irrigator frequently regards his individual interest as antagonistic to that of the community or management, insisting upon wasting water because of the mistaken belief that the more of a good thing he has the better. He thus gradually reduces the value of his land or ruins it and that of his neighbors, contesting stubbornly every effort at economy and wise management, because it interferes with his convenience. He has paid for water and he wants all he has paid for and more, awakening too late to the fact that in all this he has been struggling to do the wrong thing, because it seemed at the time easiest or cheapest. This phase of the work demands not merely engineering skill and agricultural knowledge, but the exercise of patience, tact, and firmness to the highest possible degree.

It is probable that as irrigation systems develop, as the country grows older, and experience is acquired, the good practices will crystallize into customs and the customs into laws or regulations, making it easier to control the distribution of water, but at the present stage of the development under the reclamation act, with new officers and employees in a new country with almost unknown soil and climatic conditions, with families from all parts of the United States and from abroad, with irrigators who have never irrigated before, with customs uncrystallized, with laws and court decisions confusing and apparently contradictory, it is easy to see that there is no bed of roses for the water master, who must operate hundreds of miles of new ditches, delivering water to hundreds of new farms, through or by means of hundreds of structures, including headgates, flumes, culverts, and with bridges, crossings, etc., to be maintained.

The water master, or the man who manages a large complicated system of hundreds or thousands of small farms, who must plan out day by day the schedule of distribution, who must guard against loss, be keenly vigilant for possible breaks in the system, and who takes the place of Providence for a community, is the most abused individual in the community.

AMOUNT OF WATER USED.

The phrase "duty of water" is used frequently indicating the amount of water required during the year or crop season for successful irrigation. The duty of water is usually expressed in depth over the surface, for example, the statement that the duty of water is 3 acre-feet means that during the crop season an amount of water has been applied sufficient to cover an acre to a depth of 3 feet. As the acre consists of 43,560 square feet, a duty of water of 3 acre-feet corresponds to the use of 130,680 cubic feet per acre during the year, or nearly a million gallons (977,550 gallons).

The use of water is also frequently expressed by a statement that 1 second-foot will irrigate 100 acres, more or less. This means that a stream 1 foot wide and 1 foot deep flowing at the rate of 1 foot per second, or in other words, 1 cubic foot of water per second flowing throughout the irrigating season will water 100 acres. By a simple arithmetical computation, it will be found that 1 cubic foot per second flowing for 24 hours will cover an acre to a depth of very nearly 2 feet (1.98 feet). In other words 1 second-foot is nearly equivalent to 2 acre-feet per day; thus, if the irrigating season is 90 days in length, 1 cubic foot per second for 90 days will amount to a delivery of nearly 180 acre-feet, or cover 100 acres to a depth of 1.8 feet.

NECESSITY OF GOOD MANAGEMENT.

The value of the crop produced and the consequent ability of the farmers to return the cost of the investment are dependent directly upon water being received on each farm in proper quantity and at the right time. If too much water is applied the crops will be correspondingly injured, the available soluble salts in the soil will be washed out or brought to the surface, the land depreciate in value, and large areas will be destroyed. With intensive cultivation and the crop production in the more valuable fruits, berries, or vegetables under ideal conditions, the yield may be several hundred dollars an acre. By a slight error in handling the water the crop value may be lessened by a hundred dollars an acre or more.

Although the net product per acre may appear to be large and satisfactory, and it is impossible to prove that higher values might have been reached, yet the man who thoroughly understands the situation appreciates that there has been a loss of $100 per acre, which is directly attributable to lack of good management, and that under better conditions higher values would have been attained by the farmers. This possible reduction of crop values in a highly developed agricultural area of say 10,000 acres at $100 per acre

means a loss to the community of a million dollars, or, rather, under better or more successful management of the water, the net return of the community might have been $1,000,000 more during the season.

This is by no means a fanciful idea. The study of ditch management and crop production in irrigated regions shows that in many instances there has been a shortage of water at a critical time, due to lack of forethought or skill on the part of some one.

The average farmer does not appreciate what this has meant to him, as he is apt to rarely figure out these larger matters with any degree of precision, and has been accustomed to disappointments in his crops so often that he regards such matters as inseparable from agriculture. If the crop looks fairly well he frequently goes no deeper. Possibly never having seen a full-crop production under excellent conditions he has no standard by which to judge.

This matter was well illustrated by an experienced irrigation manager who examined one of the large projects in Wyoming where the farmers for several years had been what they considered fairly successful. They had raised profitable crops and had succeeded in getting along with constant temporary repairs to the main canal. He took the history of a single season's operation and number of days that the canal was out of service through accidental but preventable breaks, and figured on a conservative basis what would have been the crop products had the works been maintained in excellent order by skilled men. He showed that had fire swept through the country and destroyed every visible improvement in the towns of the vicinity the loss to the entire community would have been less than had actually resulted from preventable failure to operate the canals properly. The spectacular view of a burning barn or storehouse rivets public attention upon this definite loss, but the gradual and unimpressive delay in development of the crop day by day is not noticeable. While all of the neighborhood would rush to aid the owner of the burning barn, yet no one knows or apparently cares while the valuable fruits or other crops are being imperceptibly reduced in value to a far larger degree.

FERTILIZERS.

One of the fallacies which must be continually met and overcome with these new men is that by applying water artificially to the soil the processes of farming are made easier and that there is no need of applying fertilizer. Statements are often made in popular publications to the effect that the irrigating streams not only furnish to the plants the needed water but also bring fertilizers and enrich the soil. The Nile Valley, in Egypt, is frequently cited as an instance where it is alleged that through centuries agriculture has been practiced without impoverishing the soil, the rich mud left by the river

giving all the necessary elements required for the growing crop. This, however, is true in part only. The soils of Egypt for best results must be fertilized by supplying the lack of some of the elements of plant food not brought by the Nile.

As a matter of fact, irrigation can not take the place of cultivation, and it is not a lazy man's form of agriculture, but quite the reverse. Cultivation may take the place of irrigation to a certain extent, and it has been found that thorough cultivation reduces the need of water, but neither cultivation nor application of muddy waters will bring to the soil all the needed constituents which must be had to obtain the largest and best growth of plant or fruit.

During the first few years the crop returns from the formerly unworked soil are frequently large, but to preserve the valuable qualities experience has shown that some of the constituents of the soil must be conserved and others added. In other words, it is impossible to take large crops away from the fields year after year unless the necessary food is supplied to the plants. The successful irrigator must not only cultivate his fields, apply water sparingly, but must fertilize, supplying those materials which experience has shown are most beneficial to the crops. He should strive to retain or renew in the soil the useful constituents placed there by nature and supplement these where needed.

Most of the soils of the arid region contain a large proportion of soluble mineral salts. The rains have not been sufficient to wash these entirely away and they remain fairly uniformly diffused throughout the soil. Some of these salts are extremely valuable as plant food, but if at any point in the field they are in excess, there plant life is destroyed. The chief deficiency among these, however, appears to be in the phosphates. It is sometimes essential to supply this lack, even though there is a large quantity of the salts of soda and potash.

The problem of obtaining the phosphates should not be a very difficult one as throughout the arid region are large deposits of the rock carrying the necessary supply and the smelters or other industries, as a by-product, can produce unlimited quantities of the acids necessary to put this phosphate into soluble or accessible form. The development of the industry has, however, not proceeded to a very notable degree, because of the slowness of the farmers to recognize the fact that fertilizers of this kind are valuable and the fear that, if it is generally known that fertilizer should be used, this will add to the discouragement of the new farmers.

ALKALI.

The excess of what is otherwise a valuable fertilizing element is also a matter which must be of serious concern. The natural salts,

easily soluble and widely distributed through the agricultural soil, may be concentrated by careless handling of the water and bring about a condition which is covered by the general term "alkali." These salts appear on the surface of the ground, usually as a thin white crust, looking in the distance like snow (pl. 2, fig. 2). The appearance of the salts on the surface is sometimes preceded by an excessive crop yield, followed by diminution and burning out of the plants, and then by the white patches taking possession of the field. This is commonly known as the white alkali. Another appearance, less frequent, is that of irregular black patches of a peculiar, almost oily substance, as though a quantity of crude petroleum had been scattered over the field, destroying the crop and leaving a black stain. This is the dreaded black alkali, which is more difficult to eradicate.

The white alkali is of the nature of gypsum, mostly sulphate of soda, while the black alkali consists of mixtures of similar salts in which the bicarbonate of soda predominates. Their destructive effect can be prevented by care and vigilance, and remedies can be applied, though at very large expense, sometimes too costly for the value of the land. In this, as in many other evils, an ounce of prevention is worth a pound of cure.

A study of the origin of the alkali shows that as a rule where water has been applied to lands in excessive quantities it has dissolved some of the valuable salts, and, seeping through the ground, has finally come to the surface perhaps a mile or more away. Evaporating, the water has left its load of soluble material, for a time enriching the soil at this locality, as illustrated in the large crop growth for a short period. The process still continuing, the salt has accumulated to such an extent as to be visible.

The remedy lies in two directions:

First. In preventing excessive use of water, and,

Second. In systematic drainage, to take away any excess of water.

The first is mechanically the easiest, but from the human standpoint the most difficult, as it is impossible to convince the average newcomer, who first sees the wonderful results of irrigation, that it is possible to apply too much water and to ruin his own or his neighbor's field.

He can not see that he is washing out slowly but surely the constituents of the soil which are vital to his continued success. It requires a careful analysis to show that these salts, which would cost him, say, $100 per acre to apply, can be quickly taken away by a little carelessness, and the true value of the land reduced. He is less willing to admit that the excess water which has drained or percolated from his land, carrying off what is valuable to it, is at the same time concentrating the salts in the soil of his neighbor until its value

is reduced in the opposite direction by becoming overloaded with what he has lost.

The average experienced irrigator, seeing that something is wrong, and not recognizing that he himself is creating the mischief, clamors for drainage. If he could have his way he would develop a system of drains such that by having a steady stream of water flowing to the farm, there would be an almost equal stream flowing away, washing over or percolating through his soil. Such condition would result in a few years in leaching the land to a mere insoluble skeleton. This future contingency seems very remote in comparison with the ease and pleasure of having an abundant stream of water available at all times to turn to the fields or running out among his plants.

These conditions are given at this time as illustrating the problems which are incident to the present stage of development of the reclamation projects. On each of these a similar period of education of the individual and of the community must be passed through. There must be taught what is essentially a new art to men and women who have acquired experience along other lines. Many of the farmers must unlearn some of the things taught from boyhood, but as time goes on, and as experience is had in the new home and under the new climatic conditions, the importance of this matter gradually dawns upon the settler. As payments are made and the responsibilities of ownership become more deeply impressed, he sees the necessity of various regulations and becomes more ready to cooperate in the general welfare.

The same lessons, however, must be learned on each of the projects, and although one group may have passed through bitter experience in losses through following wrong methods, another group must learn the same lesson in the same way.

LOCATION OF WORKS.

Reclamation projects, as before stated, have been begun in each of the Western States and Territories, and there is given in the following pages a review of the present condition of these, arranging the descriptive matter alphabetically by States, and giving concisely the physical features which are of interest or concerning which questions are usually asked by the student of engineering. The location of these projects is shown by the small map (fig. 1) which indicates by the heavy black spots the relative position and outline of the projects which are described. The structures are of all kinds and descriptions, and on each project there may be from 3,000 to 5,000 distinct pieces of work, these ranging from a great storage dam or tunnel, costing a million or two million dollars, down to the smaller diversion dams, headgates, flumes, bridges, culverts, and almost innumerable other minor works. These are scattered over an area of from 20 to 200

miles in length, or even more. Each must be designed, built, watched, and maintained individually.

In the description that follows only a few of the larger features are mentioned, and it must be borne in mind that on most of the projects there are hundreds of miles of small distributing ditches and thousands of minor works such as farmers' headgates and flumes, each of which is important to some one man or group of men, but

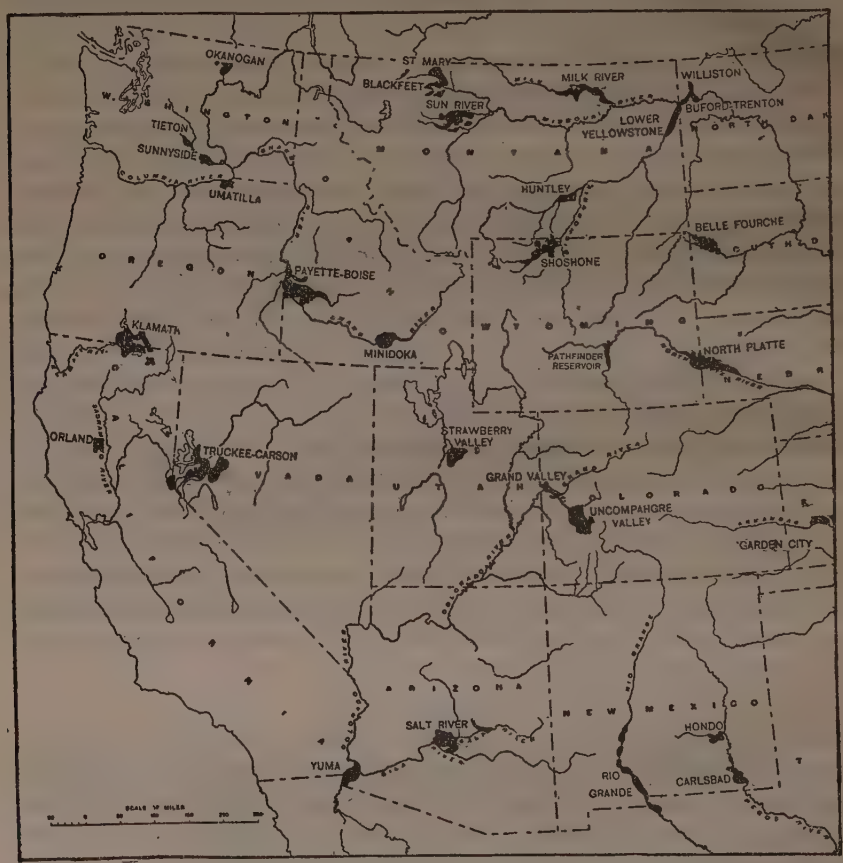


FIG. 1.—Principal irrigation projects in the western United States.

which forms merely a part of the highly elaborate system of controlling, diverting, and distributing the water.

Arizona, Salt River Project.—The principal feature of this project is a storage dam at Roosevelt, Ariz. (pl. 3), creating a reservoir with an area of 25.5 square miles, and a capacity of 1,284,000 acres of 1 foot in depth. The Roosevelt Dam is of rubble masonry 280 feet high, 235 feet long on the bottom, and 1,080 feet long on top. Its purpose is to regulate the flow of Salt River. When needed for irrigation the water is allowed to flow down the river from the dam for 40 miles,

1. DESERT COVERED WITH SAGEBRUSH, ILLUSTRATING CONDITION OF LANDS BEFORE WATER IS APPLIED.

2. IRRIGATED VALLEY AFTER SAGEBRUSH HAS BEEN REMOVED AND WATER INTRODUCED.

1. TYPICAL SETTLER'S HOME, SHOWING CULTIVATION FOLLOWING IRRIGATION.

2. ALKALI FLAT, FORMERLY VALUABLE FARM, NOW RUINED BECAUSE OF CARELESS IRRIGATION.

where it is diverted by means of the Granite Reef Dam into two canals, one on each side of the river. These canals carry water by gravity to about 170,000 acres of land in the vicinity of Phoenix and Mesa. The Granite Reef Dam is a rubble concrete weir 38 feet high and 1,100 feet long. The irrigation system includes about 499 miles of canal.

A power canal above Roosevelt Dam about 18½ miles long, having a capacity of 225 second-feet, has been constructed and used to develop 4,500 horsepower which has been used by all the accessory plants incidental to the work of construction. On this line are tunnels aggregating a total length of 9,780 feet. A power house and a transformer house have been constructed immediately below the dam, and the power developed is transmitted electrically about 80 miles down the valley, where it will be used to pump water from underground sources to extend the irrigable area to about 50,000 acres of high lands in the Gila Indian Reservation and in Salt River Valley, and for drainage purposes. A large amount of power will be available for other purposes. A cement mill erected and operated by the Government furnished the cement used in the construction work, the dam alone requiring about 280,000 barrels.

The lands under this project surround Phoenix, the capital of the State. The general elevation is 1,000 to 1,300 feet above sea level; temperature, maximum 120°; minimum, 20°; mean, 70°; rainfall, 3 to 10 inches. The watershed area is 6,260 square miles, with an additional 6,000 square miles on Verde River. The average annual rainfall on watershed is from 10 to 20 inches, and the estimated annual run-off of watershed is 804,000 acre-feet at Roosevelt Dam and 586,000 acre-feet from the Verde. The duty of water is 4 acre-feet per annum.

The valley soil is an alluvial deposit of great fertility and adapted to the cultivation of a wide variety of crops, including those of the temperate and semitropical zones. The public lands in the project have all been filed on, but there are many large holdings of private lands which must be subdivided and sold to actual settlers, as no water right can be sold for more than 160 acres under the reclamation act.

The Roosevelt Dam is now completed, and the remainder of the project will probably be completed by the end of the year 1912. Water is being furnished to about 131,000 acres of land and this area will be increased by several thousand acres during each succeeding season. During 1910 the beet-sugar industry has been proven a success in this valley, netting the growers handsome returns even under adverse conditions. Forage and grain crops, fruits, and vegetables of all kinds produce well and command high prices in the local markets.

Arizona-California, Yuma Project.—The diversion of the waters of Colorado River into two canals, one on each side of the river, is accomplished by means of Laguna Dam, a structure of the Indian weir type, about 10 miles northeast of Yuma, Ariz. This dam was completed in March, 1909. It is about 19 feet high, 4,780 feet long, and 260 feet wide up and down stream (pl. 4. fig. 1). By a unique arrangement at the headgates of the canals the waters of this muddy stream are drawn off comparatively clear. The distribution system consists of 100 miles of canals. A complete system of levees with a length of 73½ miles has been constructed to protect the bottom lands from overflow, and a pumping system will be utilized to remove the surplus waters from the low-lying areas.

On the Indian reservation on the California side of the river 173 farm units were opened to entry on March 1, 1910, and during 1910 many of the entrymen cleared and leveled their farms. The cost of the water right is $55, payable in not more than 10 annual installments, with an annual charge of $1 for operation and maintenance. There is also a charge of $10 as the price of the Indian lands, payable in not more than 10 annual installments.

The bottom lands comprise 17,000 acres in the Yuma Indian Reservation in California, 20,000 acres in the Gila River Valley in Arizona, and 53,000 acres in Colorado River Valley in Arizona. When the system is extended to include the mesa or table lands south of Yuma and east of the bottom lands in Arizona, about 40,000 acres of practically frostless land will be available for the cultivation of oranges, lemons, grapefruit, limes, olives, vegetables, etc.

The soil of the lowlands is a rich, alluvial deposit and produces very heavy crops when water is applied. Alfalfa, grains, vegetables, sugar beets, nuts, melons, fruits, cotton, cane, corn, etc., are grown.

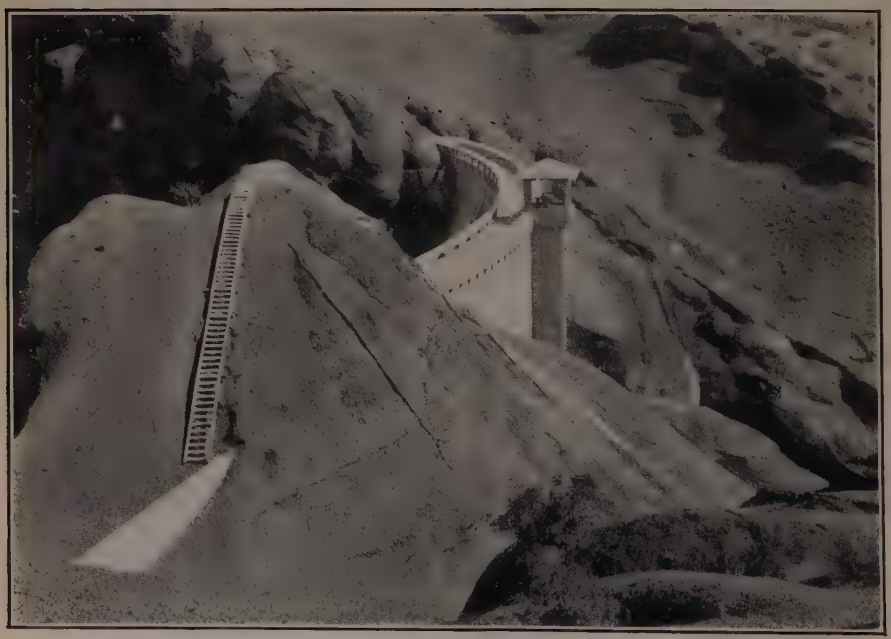
The watershed area is 160,000 square miles and the estimated annual run-off is 15,400,000 acre-feet. The lands lie at an elevation of 100 to 300 feet above sea level, and the temperature ranges from 22° to 118° above zero.

California, Orland project.—The reclamation of 14,000 acres of land lying about 90 miles north of Sacramento is involved in this project. The lands when watered are fertile, although their use for many years for wheat growing has deteriorated them for ordinary agriculture. The soil is a gravelly loam, and with irrigation and the prevailing climatic conditions it has been demonstrated that the land is excellent for the production of alfalfa, nuts, including the almond and English walnut, and both citrus and deciduous fruits. The general elevation is from 175 to 380 feet above sea level; the temperature, maximum, 120°; minimum, 26°; average annual rainfall on the irrigable lands, 17 inches. The duty of water is 3 to 3½ acre-feet per annum. The watershed area is 790 square miles. The

1. ROOSEVELT DAM, ARIZONA, AT THE TIME OF THE DEDICATION BY EX-PRESIDENT ROOSEVELT, MARCH, 1911.

2. ROOSEVELT DAM, LOOKING DOWNSTREAM.

1. LAGUNA DAM ON COLORADO RIVER, LOOKING FROM NEAR THE HEADGATES ON THE CALIFORNIA SIDE ALONG THE AXIS OF THE DAM TO ARIZONA.



2. EAST PARK DAM ON ORLAND PROJECT, CALIFORNIA: CONCRETE STRUCTURE FOR REGULATING FLOODS.

average annual rainfall on the watershed is 25 inches, and the estimated annual run-off on watershed 543,000 acre-feet.

The engineering features consist of a storage reservoir controlled by the East Park Dam on Stony Creek, at a point about 40 miles above Orland (pl. 4, fig. 2), and a diversion dam situated at Miller Buttes for turning water into two canals, one on each side of the creek, covering lands in the vicinity of Orland. The storage dam is of concrete masonry, gravity section, 139 feet high from bedrock, 60 feet long on the bottom and 250 feet long on top. The canal system includes 25 miles of main canal and 80 miles of laterals. The farmers are pledged to dispose of their holdings in excess of 160 acres to bona fide settlers under the terms of the reclamation act.

Colorado, Grand Valley Project.—This is planned to irrigate about 53,000 acres of land in Mesa County, Colo. The work involves the construction of a diversion dam in Grand River, about 60 miles of main canal, with a series of short tunnels on the first few miles of canal having an aggregate length of about 20,000 feet. It is probable that considerable power will be developed at drops in the canal, and used to pump water to elevations above the main canal.

The average elevation of the irrigable area is 4,700 feet above sea level; the temperature ranges from 15° below to 100° above zero, and the rainfall on the irrigable area is from 6 to 11 inches annually. The watershed area is 8,550 square miles.

The soil is largely red mesa sand, black bottom sandy loam, and adobe. The apple and peach orchards of the Grand Valley bottom lands are famous, the crops sometimes selling for more than $1,000 per acre per annum. Strawberries and cantaloupes are usually grown between the rows while the orchards are growing, also potatoes and other vegetables; alfalfa and sugar beets are also grown.

Colorado, Uncompahgre Valley Project.—Here the waters of Gunnison River are diverted by means of a tunnel 30,645 feet in length, cross section 10 by 11 feet, cement lined, with a capacity of 1,300 second-feet. The tunnel passes through the mountains to Uncompahgre Valley, where its water is used to supplement the local supply and extend the irrigable area to about 140,000 acres of land. The tunnel was commenced in 1904 and carried water in 1910. There are 330 miles of canals in the distributing system.

The lands to be irrigated in Montrose and Delta Counties have a general elevation of 5,000 to 6,400 feet above sea level and the temperature ranges from 20° below to 98° above zero. The watershed area is 4,350 square miles, and the estimated run-off of watershed is 1,610,000 acre-feet. The rainfall on the irrigable area is from 6 to 12 inches, and the rainfall on the watershed ranges from 7 to 20 inches.

The lands for which water is now available are mainly in private ownership. The farm unit varies from 40 to 80 acres, and the duty

of water is 4 acre-feet per annum at the farm. About 60,000 acres are suitable for raising apples and peaches. Orchard lands produce as high as $500 per acre in the valley. The bottom lands, comprising from 80,000 to 90,000 acres, are adapted to the growing of alfalfa and sugar beets.

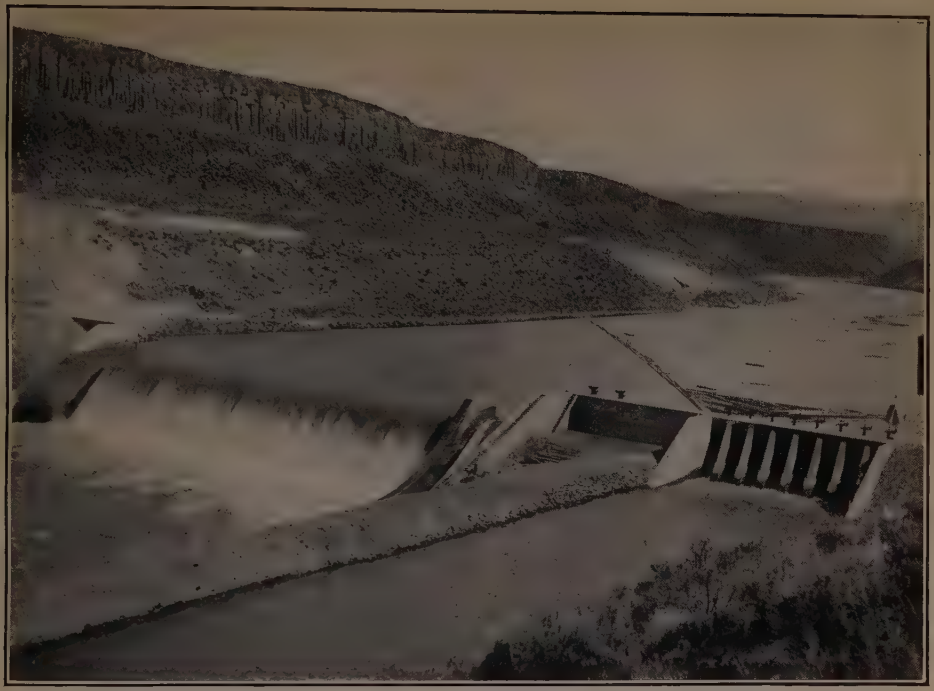
Idaho, Boise project.—When fully developed the Boise project will reclaim approximately 243,000 acres and will supplement the supply for about 79,000 acres of land in the fertile valleys of the Boise and Snake Rivers in southwestern Idaho. The general elevation is 2,500 feet above sea level, and the temperature ranges from 28° below to 107° above zero. The thermometer rarely reaches zero, however, and freedom from wind marks the winter months. The summers are long, sunshiny, and warm, and with irrigation promote the most rapid vegetable growth. The soil is largely of volcanic origin, free from rocks, easily worked, and rich in the necessary mineral constituents. With rotation of crops and the addition of vegetable mold it becomes very productive.

Farms in a good state of cultivation produce 3 to 8 tons of alfalfa per acre in three cuttings, 2 to 5 tons of clover, 50 bushels of wheat, and 75 bushels of oats. After the last cutting the fields furnish pasturage. Both clover and alfalfa seed yield good crops. Apples, prunes, and small fruits produce well and are shipped in quantities to eastern markets. Sugar-beet culture is also profitable.

Storage reservoirs on the headwaters of the Boise River are necessary and are being built. A diversion dam (pl. 5, fig. 1) has been completed on Boise River, 8 miles above Boise, diverting water into a canal irrigating lands under it and supplying Deer Flat reservoir in the vicinity of Nampa, which has a capacity of 186,000 acre-feet. The watershed area of the Boise River is 2,610 square miles; the average annual rainfall on watershed is 25 inches, and the estimated annual run-off of watershed is 2,190,000 acre-feet. The average rainfall on the irrigable area is 12.7 inches.

Idaho, Minidoka project.—The irrigable area under the Minidoka project consists of about 76,700 acres under a gravity system and 48,000 acres under a pumping system. The lands lie on both sides of Snake River, in the southern part of Idaho, in Lincoln and Cassia Counties.

The works include a diversion, power, and storage dam on Snake River at a point about 6 miles south of Minidoka, Idaho, and two canal systems (pl. 5, fig. 2), one on each side of the river, heading at the diversion dam and covering lands in the vicinity of Acequia, Rupert, Heyburn, and Burley. Power is developed at the diversion dam for generating electrical energy for pumping water to lands on the south side of the river too high to be reached by a gravity system.



1. DIVERTING DAM IN BOISE RIVER, IDAHO.

2. MAIN NORTHSIDE CANAL, MINIDOKA PROJECT, IDAHO, TYPICAL OF THE LARGER IRRIGATION CANALS, WITH POWER TRANSMISSION LINES LOCATED ON THE BANK.

1. PORTION OF RECLAIMED DESERT, SHOWING ONIONS RAISED FOR SEED ON THE HUNTLEY PROJECT, MONTANA, FORMERLY PART OF THE CROW INDIAN RESERVATION.

2. CROP OF ALFALFA ON SUN RIVER PROJECT, MONTANA, ON LANDS ORIGINALLY DESERT.

The dam has a height of 86 feet and a length of 736 feet and is of the earth and rock fill type. It has a spillway 2,385 feet long. The distribution systems include 513 miles of canals. The power and transmission lines will have a length of from 13 to 20 miles.

The soil is sandy loam and volcanic ash fairly free from alkali, and exceedingly fertile. The sandy soil is particularly adapted to the raising of alfalfa, potatoes, beet and other root crops, as well as melons, strawberries, etc. It is also especially adapted to the cultivation of sugar beets.

The general elevation is 4,200 feet above sea level. There is an ample water supply. The watershed area is 22,600 square miles, and the estimated annual run-off is 8,000,000 acre-feet. The average annual rainfall on the irrigable area is 14 inches.

The cost of water right is $22 and $30 per acre, payable in 10 annual installments, and the operation and maintenance charge for 1910 was 75 cents per acre for the gravity system. The building, operation, and maintenance charges for the high areas to which water must be pumped have not been fixed.

Kansas, Garden City project.—This project consists of a pumping system for the recovery of underground waters, which are delivered into a conduit leading to a distributing canal known as "The Farmer's Ditch." The plant consists of 23 small pumping stations, each operated electrically from a central power station. There are 10,677 acres of irrigable land lying in the vicinity of Garden City on the north side of Arkansas River. The soil is a rich prairie loam capable of high cultivation and adapted to the raising of grain, sugar beets, cantaloupes, alfalfa, and other crops of the plains region. The average elevation of the area under this project is 2,925 feet, and the temperature ranges from 20° below to 105° above zero. The water-right charge is $37.50 per acre of irrigable land, and the farmers are also required to pay an annual maintenance and operation fee which at present amounts to $2.75 per acre. The project has not been a success because of the failure of the farmers to economically use the relatively expensive water.

Montana, Blackfeet project.—This was planned for the reclamation of 50,000 acres of land in the Blackfeet Indian Reservation, Mont., and the ultimate reclamation of 133,000 acres total under five proposed canals. The first construction involves the diversion of water from the left bank of Two Medicine River immediately below the confluence of Little Badger Creek and carrying this to lands in the east-central portion of the reservation, east of the town of Cut Bank. These lie at an elevation of approximately 3,850 feet, and the temperature ranges from 40° below zero to 100° above. The soil is a sandy loam, producing abundantly with sufficient moisture. The average rainfall is about 16 inches, but varying materially. Some hay and

grain and excellent pasturage are produced without irrigation. The main canal and a portion of the distribution system of the Two Medicine unit were the first completed.

Montana, Flathead project.—Irrigation works for the land allotted to the Indians and for such additional lands as may be opened to entry are being constructed on the Flathead Indian Reservation in Montana. Upward of 150,000 acres will be covered by the eight principal canals and several minor systems. Construction work has been in progress to cover three units—the Jocko unit, comprising 6,000 acres; the Polson unit, 3,000 acres; and the Mission unit, 6,000 acres. The canals for the Jocko north side unit have been completed; also for additional 2,000 acres on the Jocko south side unit and for the Mission unit of 6,000 acres. The allotments of lands to the Indians have been made and the remaining lands, which may be irrigated from the canals being constructed primarily for the Indian allotments, have been entered.

The average elevation of the land is about 2,800 feet above sea level, and the temperature ranges from 30° below zero to 96° above. The soil is clay, forest loam, and gravelly loam, and fair crops of hay, grain, and fruits are usually produced without irrigation, the average annual rainfall being about 15 inches. With irrigation, alfalfa and all kinds of grains, vegetables, and fruits in variety peculiar to this altitude are produced in abundance.

Montana, Huntley project.—About 30,000 acres of irrigable land, located along the south side of Yellowstone River, have been reclaimed, these being formerly a part of the ceded strip of the Crow Indian Reservation. Settlers are required to pay $4 per acre to the Indians—$1 at the time of entry and 75 cents annually for four years, beginning with the second year. In addition to this the Government charges the settler the cost of building the irrigation works, which is $30 per acre, payable $3 per acre per annum for 10 years. A further annual charge of 60 cents per acre for operation and maintenance is made.

The general elevation of this part of Montana is 3,000 feet above sea level; its climate is mild and the soil, varying from light sandy loam to heavy clay, produces abundant crops when properly watered. The principal products are alfalfa, forage, cereals, sugar beets, vegetables, apples, and small fruits. The farm units vary from 40 to 160 acres, depending upon location, and average 40 acres of irrigable land. The irrigated land in this vicinity sells from $75 to $200 per acre, according to the state of cultivation and the crops grown.

The engineering works consist of a system of canals having a length of 268.5 miles, delivering water to each farm. The headworks, culverts, and other structures are of reinforced concrete and

the three tunnels with an aggregate length of 2,654 feet are lined with cement. The pumping plant near Ballantine is a novel feature, as the drop of water from the main canal is made to lift a portion of the water to a higher level to supply the high-line canal. This is accomplished by means of vertical turbines and centrifugal pumps mounted on the same shaft, and the operation is nearly automatic.

Montana, Milk River project.—It is possible to reclaim about 248,000 acres of land in the Milk River Valley between Chinook and Glasgow, in Chouteau and Valley Counties, Mont., of which about 50 per cent is public land. The average elevation is 2,200 feet above sea level and the temperature varies from 45° below zero to 100° above. The soil is well adapted to the raising of hay, grain, vegetables, alfalfa, sugar beets, and other products of the north temperate zone. The Dodson Dam on Milk River has been completed and water is being diverted into the canals on each side of the river, the south canal taking water to about 10,000 acres, covering lands extending from Dodson to Nelson Lake Reservoir. From here it is expected to construct another canal to cover lands toward Glasgow.

In addition to the ordinary discharge of Milk River the water supply will be supplemented from St. Mary Lake. The discharge of St. Mary Basin will be stored and conducted by a canal 25 miles across the divide to the headwaters of Milk River. The engineering features involve storage and several diversion dams, 375 miles of main canal, and an extensive lateral system.

Montana, Sun River project.—The lands are located in Teton, Lewis and Clark, Chouteau, and Cascade Counties, about 25 miles from Great Falls. Sun River Valley is about 70 miles long and from 1 to 5 miles wide. The ultimate development of the project includes the reclamation of 276,000 acres of land. A compact body of 16,000 acres, known as the Fort Shaw unit, has been opened to entry and rapidly settled.

The principal crops are alfalfa, hay, grain, vegetables, and sugar beets. The general elevation is 3,700 feet above sea level, and the temperature ranges from 40° below zero to 100° above zero. Fine grazing lands surround the project. The farm units vary from 40 to 160 acres of land. Wherever practicable. a tract of grazing land is included in the farm unit.

The watershed area consists of 850 square miles on Sun River and 290 square miles on Deep Creek, and the estimated annual run-off is about 700,000 acre-feet. The average annual rainfall on the irrigable area is 12 inches.

Farms under this project are obtainable under the homestead law, subject to the charge for water of $30 per acre of irrigable land in not more than 10 annual installments. At present the operation and maintenance charge is 50 cents per acre per annum, and the sum of

$3.50 per acre is due and payable at the time of making entry. An interesting feature in connection with this project is the establishment of villages every 6 miles. In connection with the Fort Shaw unit already opened the villages of Fort Shaw and Simms have been established.

Montana-North Dakota, Lower Yellowstone project.—Water is diverted from Yellowstone River at a point 18 miles northeast of Glendive, Mont., and will ultimately irrigate about 65,000 acres of land, for 40,000 acres of which the works have been completed and the water is now available. Two-thirds of the lands to be irrigated are in Montana, the balance in North Dakota.

The general elevation is 1,900 feet above sea level, and the temperature ranges from 30° below to 100° above zero. The soil is a deep sandy loam, easy to cultivate. Alfalfa, the great forage crop of the West, is especially adapted to the soil and climate. Small grains are raised with success and it is believed that sugar beets will be a profitable crop. The average rainfall is 16 inches. Surrounding the project is one of the largest and best grazing areas in the United States, providing a fine range for vast numbers of cattle and sheep. An abundance of lignite for fuel is found throughout this section.

The principal engineering features consist of a diversion dam on Yellowstone River 12 feet high and 700 feet long, 259 miles of canals, and the development of 290 horsepower.

Nebraska-Wyoming, North Platte project.—This is about 100 miles north of Cheyenne, Wyo., extends along the North Platte River, and includes about 129,000 acres. The average elevation is 4,100 feet above sea level, and the temperature ranges from 25° below to 100° above zero. The average annual rainfall on the irrigable area is about 15 inches. The soil is a sandy loam, quite free from alkali, and requiring 2½ acre-feet of water per acre per annum. Alfalfa is the principal crop, but cereals, sugar beets, and potatoes are successfully grown. Excellent range country borders the irrigable lands in Wyoming.

The farm unit has been fixed at 80 acres, and the building charge is $45 per acre. The watershed area is 12,000 square miles, and the estimated annual run-off of watershed at Pathfinder Dam is 1,370,000 acre-feet. The principal engineering features consist of a storage dam forming what is known as the Pathfinder reservoir on the North Platte River, about 50 miles southwest of Casper, Wyo., a diversion dam 150 miles down the river at Whalen, Wyo. (pl. 7, fig. 1), and the interstate canal, 150 miles long. Total length of canals 598 miles. The Pathfinder Dam is a concrete rubble masonry arch 218 feet high and 432 feet long on top. It is completed and the reservoir has a capacity of 1,025,000 acre-feet. The diversion dam at Whalen is a reenforced concrete weir 29 feet high and 300 feet long. A diversion

1. DIVERTING DAM ON NORTH PLATTE RIVER FOR INTERSTATE CANAL, NEBRASKA-WYOMING.

2. FLUME ON INTERSTATE CANAL, CROSSING SPRING CANYON, WYOMING.

1. CEMENT-LINED CANAL CARRYING WATER OF TRUCKEE RIVER TO CARSON RIVER, NEVADA.

2. DIVERSION DAM AT LEASBURG, NEW MEXICO, ON RIO GRANDE, AND HEAD OF CANAL FOR MESSILLA VALLEY.

dam is also planned to be constructed at Guernsey, Wyo., for diverting water into a canal to cover lands in Goshen Hole, in eastern Wyoming and western Nebraska, which are now withdrawn from entry.

Nevada, Truckee-Carson project.—This work in western Nevada is located in Churchill, Lyon, and Storey Counties. The first unit was opened in 1907, and lands are now subject to homestead entry. In addition to the land office filing fee each settler is required to pay $3 per acre annually for 10 years, without interest on deferred payments. An annual maintenance fee of 60 cents per acre is charged in addition. The first payment of $3.60 per acre must be paid at the time of filing on the land. The farm unit is 80 acres.

A dam has been built on Truckee River, near Wadsworth, to turn the flow of the stream into a canal 31 miles long (pl. 8, fig. 1), which carries the waters to Carson River. Here a diversion dam turns the waters as needed into two main canals. The first unit of this project includes more than 600 miles of canals and laterals, 50,000 feet of dikes, and the dams on the Truckee and Carson Rivers. The project in its entirety will irrigate about 260,000 acres of land and will involve the construction of several storage reservoirs and the development of power.

The climate in this valley is mild; the elevation above sea level is about 4,000 feet, and the temperature ranges from zero to 105° above. It is so dry, however, that the extremes, which seldom occur, are not injurious. The average rainfall on the irrigable area is 4 inches per annum. The soil is loam and volcanic ash, requiring 3 acre-feet of water per annum for each acre. The valley will produce the varieties of crops grown in the north temperate zone. Alfalfa, wheat, barley, and oats grow luxuriantly, and corn is also profitable. Potatoes and garden vegetables do well and find a ready market in the near-by mining towns.

The watershed area is 3,450 square miles, the annual rainfall on the watershed 25 inches, and the estimated run-off 1,000,000 acre-feet.

New Mexico, Carlsbad project.—The principal works here include the reconstruction of canals and storage reservoirs on Pecos River, in Eddy County, built to irrigate about 20,000 acres of land. These lands are in private ownership, but several thousand acres are included in excess holdings. The price of these lands varies from $20 to $60 per acre. The cost of water right is $31 per acre, payable in 10 annual installments, and the annual maintenance and operation fee is $1.35 per acre.

The general elevation is 3,100 feet above sea level, and the temperature ranges from zero to 110° above. The soil is light and sandy. The principal crops in the valley are peaches, pears, apples, cherries, small fruits, alfalfa, cotton, sweet potatoes, celery, and garden truck.

Fodder, corn, cane, and milo maize produce good crops. Stock raising is profitable, owing to the extensive range lands on the east and west.

New Mexico, Hondo project.—A reservoir has been built for the storage of the flood waters from the Hondo River, a tributary of the Pecos, to irrigate 10,000 acres of land in Chaves County near Roswell. The general elevation is 3,750 feet above sea level. The soil requires about 2½ acre-feet of water per annum. Alfalfa, corn, fruits, and vegetables produce abundantly when properly watered.

New Mexico-Texas, Rio Grande project.—This international project includes the reclamation of 185,000 acres of land, 115,000 of which are in New Mexico, 45,000 in Texas, and 25,000 in Mexico, which are provided for by the treaty proclaimed January 16, 1907.

The Leasburg Dam (pl. 8, fig. 2) for the first unit of the Rio Grande project is completed, diverting water for 25,000 acres in Mesilla Valley. It is of concrete, 600 feet long, with sluice and head gates. From the diversion dam 6 miles of canal were constructed to connect with the old Las Cruces Canal.

The Engle Dam, which is planned to be constructed across the Rio Grande, opposite Engle, will be rubble concrete gravity type, 265 feet high, 1,480 feet long on top, and will create a reservoir 190 feet deep at its lower end and 45 miles long with a storage capacity of 2,538,000 acre-feet. Work is being prosecuted rapidly.

The general elevation is 3,700 feet above sea level, and the temperature ranges from zero to 100° above. The average annual rainfall on the irrigable area is 9.5 inches. The soil requires about 2½ acre-feet of water per acre per annum. It produces abundant crops when sufficient water is applied, the principal products being alfalfa, corn, fruit, vegetables, and melons.

The watershed area is 37,000 square miles and the estimated annual run-off is 860,000 acre-feet.

North Dakota pumping projects.—On account of the slight fall of Missouri River gravity canals were not feasible, and pumping was resorted to with power generated with lignite coal, deposits of which are found in this vicinity on Government land. The power plant is located near one of the coal outcrops, the fuel being mined and delivered by gravity to the boilers. The power is converted to electricity and transmitted to the various pumping stations, some of which are 28 miles distant. On account of the unstable character of the river banks the pumps have been placed on floating barges connected to the shore by flexible pipes. The water is pumped to settling basins from which canals carry it over the lands.

The Williston unit includes about 8,000 acres of bench and valley lands surrounding Williston, but the system may be enlarged to cover 12,000 acres. The general elevation is 1,875 feet above sea level,

and the temperature ranges from 45° below to 107° above zero. The soil of the bottom lands is a heavy clay, but the bench lands are a rich sandy loam, requiring 2 acre-feet of water per acre per annum. The principal crops grown are wheat, flax, and oats. Alfalfa is profitably grown for winter feed, and sugar beets are likely to become an important crop. Small fruits do well, and dairy farms and market gardens are needed.

The building charge on this project has been fixed at $38 per acre of irrigable land, payable in not more than 10 annual installments, each not less than $3.80 per acre. An additional annual charge of 70 cents per acre is also required for operation and maintenance, and 50 cents per acre-foot of water actually pumped and delivered for irrigation in any one year.

The Buford-Trenton area embraces about 12,500 acres of bench and bottom lands bordering the north bank of the river for about 20 miles east of the Montana-North Dakota State line, and lying along the Great Northern Railroad. Water is now available for 4,000 acres. Power for the pumps on this project is developed at the main power station at Williston and is transmitted electrically over a transmission line 28 miles long.

Oregon, Umatilla project.—This is located 190 miles east of Portland, Oreg., in Umatilla County, and contains about 25,000 acres of irrigable land bordering upon Columbia River along Umatilla River.

The engineering works include a storage reservoir having a capacity of 50,000 acre-feet, supplied with flood water by an inlet canal from the Umatilla River (pl. 9, fig. 1). There are 138 miles of distributing canals. The farm unit on public lands is limited to 40 acres, and the majority of farms are 10 to 20 acres in area. The total building charge is $60 per acre, and the annual operation and maintenance at present is $1.30 per acre. The land to be irrigated all lies at an average elevation of 470 feet above sea level. Climatic conditions are favorable for the early ripening and marketing of small fruits, for which the soil is especially suited, as well as for the raising of all kinds of deciduous fruits. Alfalfa is profitably grown, but the land is too valuable for pasture crops. Not only is the land fertile in a high degree, and the climate such as will permit of the raising of high-priced crops, but the transportation facilities are of the best.

The watershed area is 1,610 square miles, the average rainfall on watershed is 20 inches, and the estimated annual run-off 530,000 acre-feet. The average annual rainfall on the irrigable area is 9 inches.

Oregon-California, Klamath project.—This differs from the other undertakings in that there has already been provided by nature a large storage reservoir, the Upper Klamath Lake in Oregon, situated at an altitude above that of most of the irrigable lands. Water

is taken from this by means of a tunnel (pl. 9, fig. 2) through a low range of hills and carried out by gravity to the fertile areas surrounding the lakes lying at lower altitude. The canals may be extended into areas in the northern end of California.

The lower lakes or marshes are supplied in part by waters originating in California, which flow northerly into Oregon. By storing the floods near the headwaters these lower lakes may be reduced in area and the available lands thus uncovered may be irrigated by the waters from Upper Klamath Lake. The project has many ramifications, waters derived from Oregon being used to irrigate lands in California, and vice versa. The first unit of approximately 30,000 acres has been placed under irrigation at a cost of $30 per acre.

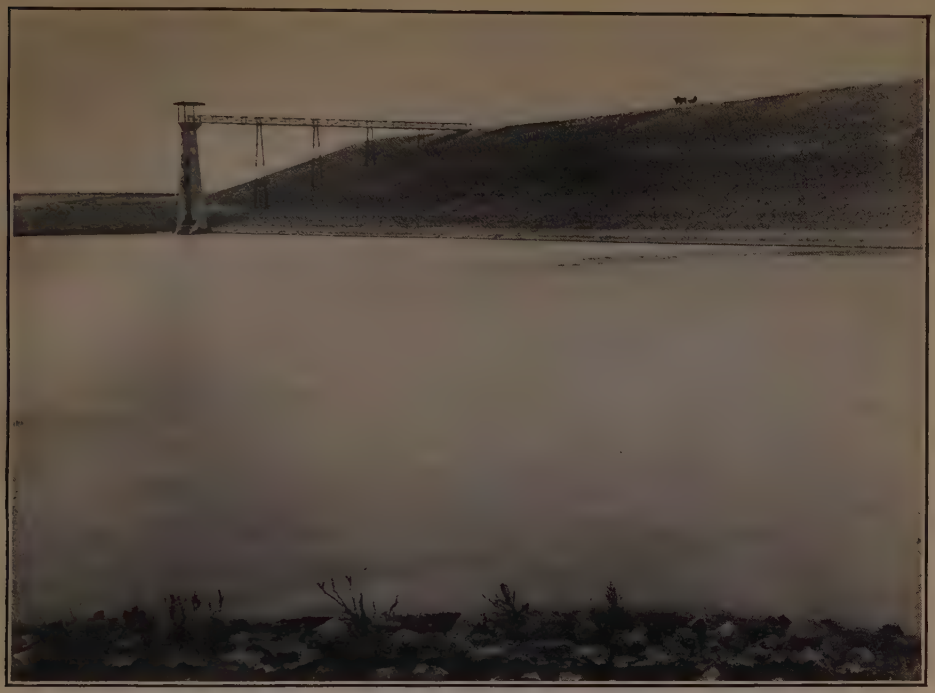
The general elevation of the irrigable area is 4,100 feet above sea level. The temperature ranges from 5° below zero to 100° above. The soil is exceedingly fertile, being decomposed basalt mingled with lake-bottom deposits. The duty of water is 1.8 acre-feet per acre per annum. The principal crops grown are alfalfa, wheat, oats, barley, rye, vegetables, and some deciduous fruits; potatoes are an important crop. The climate is especially adapted to dairying and stock raising, and forage crops grow to perfection.

The entire watershed area is 3,700 square miles, and the estimated run-off 2,124,000 acre-feet. The annual average rainfall on the watershed area is 20 inches, but the rainfall on the irrigable area is only 15 inches.

South Dakota, Belle Fourche project.—The engineering work on this project has resulted in the construction of one of the largest earth embankments in the country, built in a depression occupied by Owl Creek. It is 115 feet high, 20 feet wide on top, and more than a mile long (pl. 10, fig. 2). The reservoir thus created will be filled with water by an inlet canal (pl. 10, fig. 1) from the Belle Fourche River and will be the largest lake in the State. The watershed area is 4,270 square miles, the average annual rainfall on watershed 20 to 30 inches, and the estimated annual run-off 363,000 acre-feet.

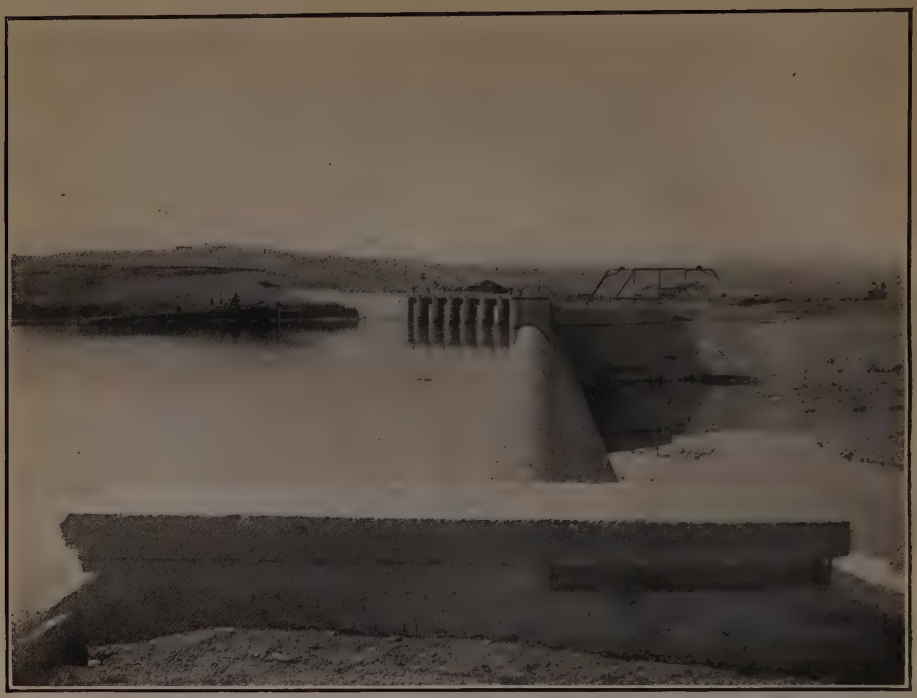
When completed this project will reclaim about 100,000 acres of land lying north and northeast of the Black Hills. Water is now available for about 47,000 acres. The farm unit on public lands is 80 acres, except within 2 miles of townsites, where it is 40 acres. Settlers are required to pay a building charge of $30 per acre and an annual charge of 40 cents per acre for operation and maintenance.

The average elevation is 2,800 feet above sea level. The climate is delightful, with little snow in winter, the temperature ranging from 20° below to 95° above zero. As in other parts of the arid region, the sensible temperature does not vary as widely owing to the dryness of the atmosphere. Fruits, such as apples, cherries, plums, and small



1. EARTH DAM FORMING COLD SPRINGS RESERVOIR, UMATILLA PROJECT, OREGON.

2. CONCRETE-LINED CANAL AND TUNNEL TAKING WATER FROM UPPER KLAMATH LAKE, OREGON.



1. DAM IN BELLE FOURCHE RIVER, DIVERTING THE STREAM INTO FEED CANAL FOR OWL CREEK RESERVOIR, SOUTH DAKOTA.

2. EARTHEN DAM FOR OWL CREEK RESERVOIR, BELLE FOURCHE PROJECT, SOUTH DAKOTA.

fruits, do well, especially on the higher portions of the project near the bluffs, and potatoes can be raised on the south side of the river, where the soil is more sandy. The main crop, however, is alfalfa and native hay for use as winter feed, the great number of cattle and sheep summer pastured on the open range surrounding the project creating a demand for alfalfa. The fruits and vegetables raised on the project are sold to the mining camps in the Black Hills.

Utah, Strawberry Valley project.—This provides for the irrigation of about 60,000 acres of land in Utah and Wasatch Counties, on the eastern shore of Utah Lake. The water supply will be obtained from a storage reservoir to be built in Strawberry Valley, about 30 miles east of the irrigable area. By means of a tunnel (pl. 11, fig. 1) about 3½ miles (19,200 feet) long the stored waters will be carried through the mountains and emptied into Spanish Fork, from which a canal 18 to 20 miles long will convey them to the irrigable area. Power created from the high-line canal is now transmitted electrically to the tunnel for drilling, and later will be utilized to pump water to lands above the gravity system and for drainage of low-lying lands.

The lands have an elevation of about 4,600 feet, and the temperature ranges from —10° to 95°. Alfalfa, hay, cereals, sugar beets, fruits, and vegetables are grown. Settlers are getting ready to plant orchards as soon as water is available. The existing canals are being enlarged to form part of the Government system.

The watershed area is 870 square miles, the annual rainfall on watershed 45 inches, and the estimated annual run-off 168,000 acre-feet.

Washington, Okanogan project.—The most interesting engineering feature is a storage dam 64 feet high and 1,000 feet long, built by the hydraulic fill process, forming a reservoir with a capacity of 13,000 acre-feet. The watershed area is 150 square miles, the average annual rainfall on watershed 17 inches, and the estimated annual run-off 37,000 acre-feet. The annual rainfall on the irrigable area is 8 inches.

This project is designed to supply water to 10,000 acres of land in Okanogan County, Wash. The soil is decomposed basalt, sand, and gravel, and is very fertile. Grain, hay, fruit, nuts, and vegetables are grown, but the principal crop is apples. The elevation of the land is about 1,000 feet above sea level. The temperature ranges from —10° to 105°. In the history of 20 years of fruit growing in the valley frost has not seriously injured the crops, and there has never been a failure with apples, peaches, plums, prunes, apricots, pears, cherries, nectarines, grapes, or any variety of small berries grown there.

On account of the possibilities of high development in this section the farm unit has been fixed at 40 acres. The building charge is

$65 per acre of irrigable land, and the operation and maintenance charge at present amounts to $1.50 per acre per annum.

Washington, Yakima project.—On the eastern side of the Cascade Mountains in the State of Washington is a succession of valleys in the upper part of the drainage basin of the Yakima River. It is estimated that with storage the water supply is sufficient for about 460,000 acres of land. Dams are being built at the outlets of several mountain lakes, the capacity of which when ultimately developed, will total 930,000 acre-feet. The development of a comprehensive system of irrigation in Yakima Valley will be accomplished by the successive construction of several units of a general project, the work being gradually extended to embrace the entire irrigable area.

Tieton unit: The lands under this unit are in Yakima County, near the city of North Yakima. The engineering features are difficult and expensive. For 12 miles the main canal (pl. 11, fig. 2) is constructed along the steep sides of the Tieton Canyon, and in five places the canyon walls are tunneled, the total length of the tunnels being more than 2 miles. The lands to be irrigated are rolling and the distribution system is also expensive. In order to replace in the Naches River the water needed to supply prior appropriations, it was necessary for the Government to construct storage works at Bumping Lake, Wash., on the headwaters of that stream. The lands in the vicinity, not more favorably situated for fruit raising, range in value from $300 to $1,000 per acre. The elevation is from 1,300 to 2,100 feet above sea level and the temperature ranges from —21° to 102°. Although a great variety of crops could be grown the lands are so valuable that it is probable the principal crops will be fruit and hops.

Sunnyside unit: The first unit of this system is now available for 11,590 acres of land in addition to the 40,000 acres under the old canal. The cost of water right is $52 per acre, payable in not more than 10 annual installments, and the operation and maintenance charge at present is 95 cents per acre of irrigable land. Work on the system consists of the enlargement and extension of the existing Sunnyside Canal, which was purchased by the Government for incorporation in a more complete system. The extension of this will cover more than 50,000 acres of new land. The average elevation is 700 feet above sea level, and the temperature ranges from —21° to 110°. The soil requires 3 acre-feet of water per acre per annum. The farm unit is 40 and 80 acres of irrigable land. Forage, hops, vegetables, and fruits are grown. The orchards of Yakima Valley are famous for their yields of fine fruits.

Wapato unit: The irrigable lands under this unit are in the Yakima Indian Reservation. There are about 116,000 acres susceptible of irrigation, 15,000 acres of which are now receiving water during high-water periods through canal systems constructed for

1. HEADING IN STRAWBERRY TUNNEL, UTAH.

2. CONCRETE FLUME BUILT IN SHORT SECTIONS FOR MAIN TIETON CANAL, YAKIMA PROJECT, WASHINGTON.

SHOSHONE DAM, WYOMING.

the Indians. The soil and transportation facilities are excellent. For the reclamation of these lands the plans provide for the enlargement of the old and new reservation canals which were built with tribal funds, the building of other canals and laterals, and the storage of over 200,000 acre-feet of water in Yakima lakes.

Kittitas unit: This unit on which no work has been done contemplates the irrigation of land in the vicinity of Ellensburg. A canal 90 miles long will bring water from the Yakima River just above Easton. The growing season is somewhat shorter here than in the lower valleys, but the lands are well adapted to diversified farming. This is the dairying section of eastern Washington, and the soil and climate are favorable for the growing of cereals, timothy, vegetables, and winter apples.

Wyoming, Shoshone project.—The most striking feature is an impounding dam at the head of the canyon of the Shoshone River in northern Wyoming, storing the waters for the irrigation of about 155,000 acres of land. This dam (pl. 12), the highest in the world, was completed in the winter of 1909–10. It is 328.4 feet high from bedrock to top of parapet walls, 108 feet thick on the bottom, and only 200 feet long on top. The reservoir created by it has an area of 6,600 acres and a capacity of 456,000 acre-feet. The diversion dam at Corbett, which turns the waters of the river through a tunnel 3⅓ miles long into the main canal, is a reenforced concrete masonry structure 18 feet high and 400 feet long. The watershed area is 1,380 square miles, the average annual rainfall on watershed 15 inches, and the estimated annual run-off is 1,150,000 acre-feet. The rainfall on the irrigable area is from 6 to 10 inches. The elevation is about 4,500 feet above sea level, and the temperature ranges from —30° to 95° The climate is dry and agreeable and the light soil produces abundantly when water is applied. Alfalfa, hay, wheat, oats, barley, and vegetables can be grown; also potatoes, sugar beets, and fruits. Large numbers of cattle and sheep are pastured on the surrounding ranges during the greater part of the year, but require feeding in the winter months, so that there is always a good home market for hay.

The farm unit varies from 40 to 80 acres of irrigable land. The building charge is $46 per acre of irrigable land, payable in 10 annual installments. The annual maintenance and operation charge at present is $1 per acre, one-tenth of the building charge, and one year's maintenance charge, or $5.60 per acre are due at the time of filing.

The surrounding mountains are covered with spruce and fir and supply the farmers with timber and the stockmen with summer range. Coal mines located in the vicinity supply cheap fuel for domestic and manufacturing purposes. Well water of good quality is found at depths varying from 30 to 50 feet.

SUMMARY.

Summarizing the foregoing statements, it may be said that during the nine years from 1902 to 1911 projects have been constructed in each of the arid States and two Territories, shown on the map on page 182, and water provided for nearly 1,000,000 acres, of which about one-half is now in use. The engineering works on the whole are completed well ahead of the actual utilization of these.

These statements are sufficient to show that the reclamation act has been a success; that the money invested is coming back; and that the great object, above and beyond the financial returns, is being reached, namely, that of providing opportunities for homes for American citizens.

ELECTRIC POWER FROM THE MISSISSIPPI RIVER.[1]

[With 8 plates.]

By Chester M. Clark.

In the Mississippi Valley, about 140 miles above St. Louis, there is being built a hydroelectric plant to utilize for industrial purposes the immense natural power of the Mississippi River. Unless before its completion in July, 1913, some other plant is constructed, propelled by a force greater for electric generating purposes than the steady flow of this great stream, the Mississippi River Power Co. will have at its command, it is believed, one of the most potent single hydroelectrical developments so far created. Its ultimate generative capacity is to be over 200,000 delivered horsepower. As part of this development there is being thrown across the river between Keokuk, Iowa, and Hamilton, Ill., a dam, which, so far as appears to be of record, will be the longest bank-to-bank river-dam yet built of solid masonry.

An undertaking of such magnitude, besides marking a step in industrial development, involves engineering features of peculiar interest. Before attempting to set these forth, however, a few words as to the history of the project may not be out of place.

HISTORY OF THE DEVELOPMENT.

As far back as 1848 there was organized what was called the Mississippi River Improvement Association, with a capital of $1,000,000, to improve navigation and harness the water power that might be developed in the process. Nothing definite is of record as having been accomplished toward this object for many years thereafter, except in the nature of preliminary observation. An examination of the geologic structure of the river bed was made. Along in 1868

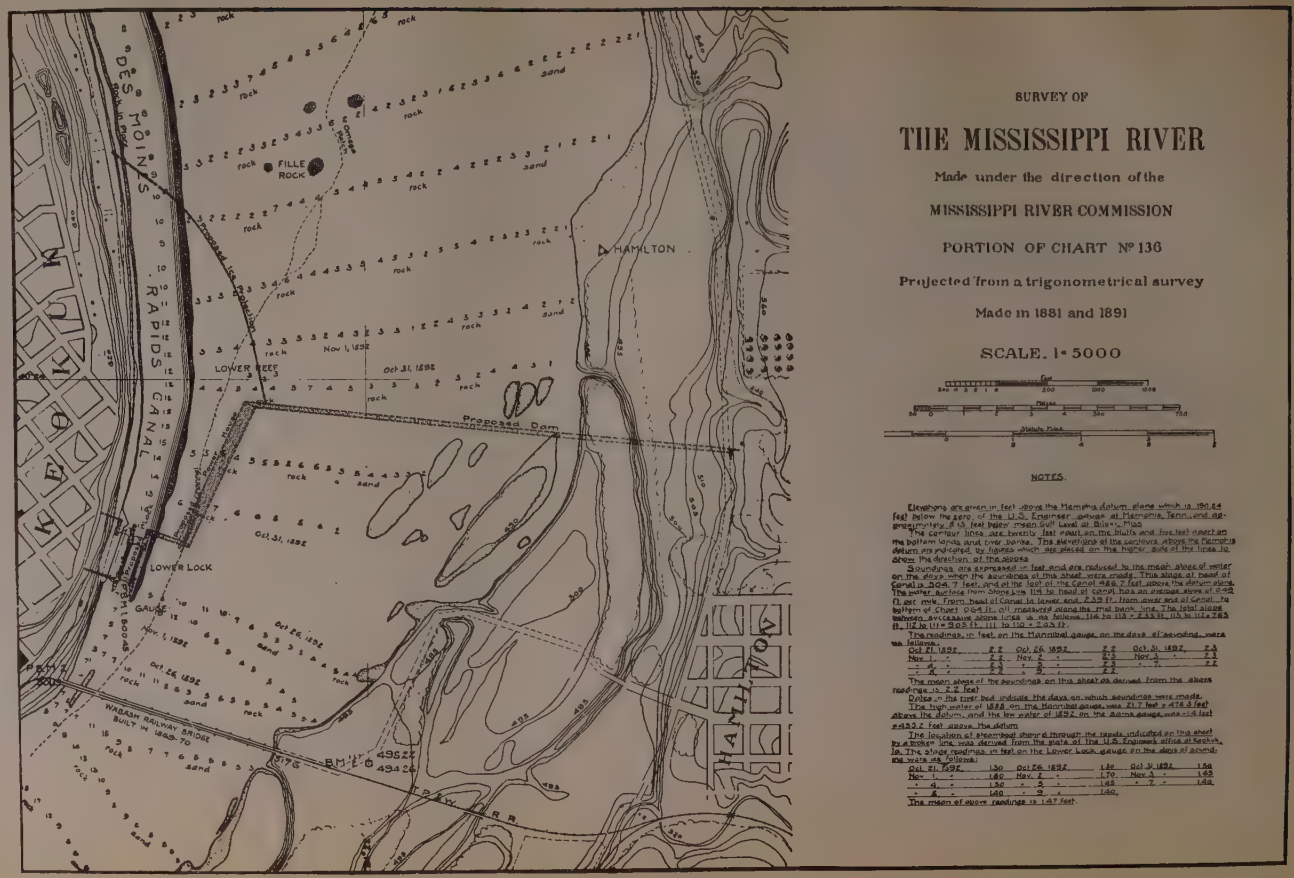
[1] In rendering available statistics and other data for this article thanks are due Mr. Hugh L. Cooper, of New York, prime mover in the enterprise, now in direct charge of the hydraulic construction of the development.

there were begun by the United States Government daily observations, which it appears have been continued, almost without break, to the present year.

Nothing in the nature of a definite enterprise was undertaken, however, until on April 18, 1900, several citizens of Keokuk, Iowa, and Hamilton, Ill., met at the State Bank of Hamilton and finally organized a company to develop and utilize the water power of the Des Moines rapids and to obtain the necessary grants for such purpose from the Congress of the United States and from the States of Illinois and Iowa. The organizers of the Keokuk & Hamilton Water Power Co. directed their first efforts to obtaining a charter from Congress, which was granted on February 8, 1901, as public bill No. 43. This act gave the right to construct, operate, and maintain a canal along the east bank of the Mississippi River between Nauvoo and Hamilton, Ill.; to erect, construct, operate, and maintain a power station in connection therewith; to erect, construct, operate, and maintain a wing dam 500 feet into the river from the head of the canal; and to make such other dams and improvements as might become necessary within said limits for the development of water power and the generation, transmission, and use therefrom of electrical energy and power. Nauvoo, noted as the seat of the first Mormon temple, is beautifully located on high ground about 12 miles above Keokuk on the opposite side of the river, and is at the head of the Des Moines rapids. The river at this point is about 1 mile wide. The building of a short dam 500 feet long into the river to gather water for a canal 12 miles long, extending down to Hamilton, Ill., it is estimated would not have permitted the development of more than 10,000 horsepower.

This project was not carried out. In its place there grew the idea of a development which, while utilizing for power purposes the entire energy of the Des Moines Rapids, would at the same time transform navigation possibly as difficult as anywhere along the Mississippi into comparatively safe and convenient water transportation. Instead of a wing dam there was substituted a concrete structure running entirely across the river from the bluffs of Keokuk to the bluffs of Hamilton and the construction in connection therewith of a single lock and dry dock and a power station capable of utilizing the full force of the flow.

This new plan was indorsed by the Mississippi River Improvement Association and by the Mississippi River Pilots' Association. Acting under authority contained in the river and harbor bill passed by Congress and approved June 13, 1902, the Secretary of War appointed a commission, of which Lieut. Col. Hodges, United States Army, and Capt. Judson, United States Army, were mem-



TOPOGRAPHICAL CHART OF SITE OF MISSISSIPPI RIVER POWER CO.'S PLANT. (LOCATION OF DAM INDICATED ON GOVERNMENT CHART.)

GENERAL VIEW OF SITE OF DAM FROM IOWA SHORE, MARCH 28, 1911.

bers. After public hearings and an investigation, the commission reported favorably on the project.

AUTHORIZATION.

In view of this favorable attitude and report, on April 21, 1904, a bill was introduced in Congress to secure the right to build a dam completely across the Mississippi at the foot of the Des Moines Rapids. This bill was favored by the legislature of the State of Illinois, which, on January 17, 1905, by joint resolution, memorialized Congress, urging its passage. The State Legislature of Iowa also indorsed the enterprise. On January 27, 1905, the bill passed the Lower House; on February 2, 1905, it passed the Senate; on February 9, 1905, it received the approval of President Roosevelt and became a law.

This law was public act No. 65, entitled "An act granting to the Keokuk and Hamilton Water Power Co. rights to construct and maintain for the improvement of navigation and development of water power a dam across the Mississippi River." It provides:

> That the assent of Congress is hereby given to the Keokuk and Hamilton Water Power Company, a corporation created and organized under the laws of the State of Illinois, its successors, and assigns, to erect, construct, operate, and maintain a dam, with its crest at an elevation of from thirty to thirty-five feet above standard low water, across the Mississippi River at or near the foot of the Des Moines Rapids, from Keokuk, Iowa, to Hamilton, Illinois, and to construct, operate, and maintain power stations on or in connection with said dam, with suitable accessories for the development of water power, and the generation, use, and transmission therefrom of electric energy and power to be derived from the Des Moines Rapids on the Mississippi River.

The United States Government had constructed in 1877, and was maintaining along the Iowa shore as an aid to navigation a dry dock, canal, and a series of three locks, the structure extending in all 11½ miles from Keokuk to a point below Fort Madison, but above the swiftest part of the rapids. The dock, canal, and locks had for years made feasible the only practicable river intercourse between points above and below the barrier.

In order to continue this means of communication, and in order that the Government might receive a return for the perpetual franchise granted the company, there follows in the bill this proviso:

> That in lieu of the three locks and the dry dock, with their appurtenances, now owned and operated by the United States, at the Des Moines Rapids Canal, the said Keokuk and Hamilton Water Power Company shall build, coincidentally with the construction of the said dam and appurtenances, at locations approved by the Secretary of War, a lock and dry dock with their appurtenances; the said lock shall be of such a kind and size, and shall have such appurtenances and equipment as shall conveniently and safely accommodate the

present and prospective commerce of the Mississippi River; the said dry dock and its appurtenances shall be such as to give space, facilities, and conveniences for the repair of vessels at least equal to those afforded by the existing Government dry dock and shops at the Des Moines Rapids Canal.

Other conditions provide for further approval by the Secretary of War and upon completion place in the United States the ownership and control of the lock, dry dock, and their appurtenances, and the operation and maintenance thereof.

As still further protection to navigation, and in the interest of fisheries, section 2 of the act requires:

That the withdrawal of water from the Mississippi River and the discharge of water into the said river, for the purpose of operating the said power stations and appurtenant works, shall be under the direction and control of the Secretary of War, and shall at no time be such as to impede or interfere with the safe and convenient navigation of the said river by means of steamboats or other vessels, or by rafts or barges: *Provided*, That the said company shall construct such suitable fishways as may be required from time to time by the Secretary of Commerce and Labor.

Under authority of this act, after the delay of preparing to finance the construction, in 1909 work was actually begun to continue until completion, it is estimated, some time before July 1, 1913.

In direct charge of the hydraulic construction is Mr. Hugh L. Cooper, of New York. The Stone & Webster Engineering Corporation, of Boston, has direct charge of the electrical installation, including the transmission and distributing lines.

CHARACTER OF RIVER BED.

The site of this dam and hydro-electric plant, as a glance at the map will show, is above the junctions with the Mississippi, of the Ohio, Missouri, and Illinois Rivers. It is at a point where the three States of Iowa, Missouri, and Illinois touch, 140 miles from Des Moines, 140 miles from St. Louis, and 220 miles from Chicago.

The dam itself is being built upon a river bed of blue limestone in a region stable from a geological point of view. The surface of the river bed at this point is naturally clean and free from the cracks and fissures of rock of igneous origin. The average depth of the river at this point is from 5 to 6 feet and the variation is slight.

Under an act of Congress July 25, 1866, a bridge joining Keokuk and Hamilton was built. This bridge crosses the river at a point 1,066 yards below the location of the Keokuk Dam. The following description of the river bed in the vicinity of this bridge is taken from page 1006 of the Report of the Chief of Engineers, United States Army, for the year 1878, Part 2:

The river in its natural condition at this place is about 2,600 feet in width at ordinary low water and about 5,500 feet in width at flood stages. The bed of the river is limestone, of the same character as that of the whole Des Moines Rapids, which extend from this place to Montrose, about 11 miles.

On page 313 of Report of the Chief of Engineers, United States Army, for the year 1867, is found a description of the Des Moines Rapids, in which the following extract appears:

This erosive action, though productive of such remarkable results, has not been carried sufficiently far to render the river through this part of its bed, available at all times for the purposes of navigation. From Fort Madison to Montrose, the river is about 2,500 feet wide, and sufficiently deep; but in the rapids its bed of limestone rock, which by some unknown cause seems to have been hardened to a greater degree than the corresponding stratum above and below the rapids, has resisted the action of the water, while its sides have given way. The result is that this mass of rock remains there, acting exactly as an artificial dam whose upper surface slopes about 22 feet in 11 miles, and conforms very nearly to the plane of stratification of the rock through which the channel is cut. The bluffs extend along the banks of the river throughout the length of the rapids, presenting a rock escarpment at the present high water-mark with a sloping gravel beach to low water, and also another escarpment of rock at 105 feet above the present water level, having, likewise, a sloping beach at its foot.

FLOW OF RIVER.

Readings of the stage of the Mississippi River at various points have been made by the United States Government since 1868. These readings have been published as part of the records of the Mississippi River Commission and of the United States Weather Bureau. Besides reading the stage of the river the Government has, through the United States Army and the Mississippi River Commission, observed at various times and at various points the discharge of the water. The results of these discharge measurements also form part of the records of the Mississippi River Commission as well as of the United States Engineers. In addition to these, various observations have been taken under the direction of Mr. Cooper. For the purpose of determining the amount of power available all of the above observations, and particularly those establishing a minimum flow, have been valuable. So far as is known to the engineers of the development, the lowest measured discharge was recorded by Montgomery Meigs, United States Civil Engineer, in September, 1891, when at a time that the commonly accepted low-water marks on Mechanics' Rock, just above Keokuk, showed water lower than the record of 1864, there was observed a discharge of 21,389 cubic feet per second. Other observations of minimum discharge are shown in the tables which follow, being the lowest records of which the engineers of the development have authentic knowledge.

Measurements at Burlington, Iowa (40 miles above Keokuk).

Date.	Stage of the river, Burlington gauge.	Measured discharge.	Method of measurement.	Measurements made under direction of—
1866.	*Feet.*	*Sec.-ft.*		
Oct. 23	[1] 1.0	36,100	Double floats	Lieut. G. K. Warren, United States Army.
1879.				
May 2	1.8	37,900	do	Maj. F. U. Farquhar, Corps of Engineers, United States Army.
May 9	1.7	38,400	do	Do.
Sept. 17	1.5	34,600	do	Do.
Oct. 4	.7	27,929	do	Do.
Oct. 10	.8	28,700	do	Do.
1891.				
Sept. 16	.2	21,389	do	Montgomery Meigs, United States civil engineer.
1907.				
Dec. 31	1.42	27,386	Rod floats	W. V. N. Powelson and Lieut. C. S. Bookwalter, United States Navy.
1908.				
Jan. 30	1.45	24,755	do	Do.

[1] In 1866 there was no standard gauge at Burlington and this gauge reading is approximate only as compared with the present gauge, which was established in 1872.

The observations listed above, purposely selected as showing the least discharge of record, have led the engineers of the development to establish in their calculations a minimum discharge of 20,000 second feet. Other observations of minimum discharge, made in 1906 under the direction of Mr. Cooper by a current meter, may serve to show the safe margin of surplus power often available over the amount calculated on the basis of the above minimum.

Measurements at Nashville, Iowa (6 miles above Keokuk).

Date.	Stage of the river, Nashville gauge.	Measured discharge.	Date.	Stage of the river, Nashville gauge.	Measured discharge.
1906.		*Sec.-ft.*	1906.		*Sec.-ft.*
Sept. 8	3.00	63,500	Sept. 28	3.05	69,700
10	3.05	64,700	Oct. 1	3.30	71,730
13	3.05	66,100	2	3.10	62,120
14	3.05	68,300	4	3.00	65,700
18	3.00	60,400	5	2.90	67,850
19	3.00	60,400	13	2.55	61,600
25	2.95	68,460			

The waters at Keokuk can not accurately be called turbulent. They are not hurled over hidden bowlders and irregular rock with the speed of a Niagara. The river has much less velocity and presents rather the smooth appearance of water running down an in-

GENERAL VIEW FROM ILLINOIS SHORE, APRIL 11, 1911. POWER-HOUSE COFFERDAM IN DISTANCE.

ILLINOIS SHORE, BEGINNING OF DAM, APRIL 18, 1911, SHOWING CANTILEVER CRANE.

clined surface (pl. —). An observer with a short metal sounding rod can hear the clear ring of the solid rock bottom all the way across. The regularity of the bottom and the rock of which it is made are charted on the facsimile of the United States Government map shown opposite page 200.

A well constructed concrete dam, power house, dry-dock, and lock on such foundations should last as long as the old Roman concrete work made of natural cement, a great deal of which has been standing 2,000 years and is still in good condition where not destroyed by the hand of man.

STORAGE OF WATER.

In the interests of navigation below the dam, particularly during the open period from March to December in each year, there are certain restrictions placed upon the complete interruption of the flow of the river. The Mississippi River Power Co., successor to the privileges and franchises of the Keokuk & Hamilton Water Power Co., is allowed to cut down the flow only during the night to 15,000 cubic feet per second for two hours, 10,000 cubic feet per second for six hours and 5,000 cubic feet per second during the balance of the time between sunset and sunrise. If the wheels do not pass the above amounts then the deficiency must be made up by letting water through the gates.

From an operating point of view these restrictions are not a gross handicap, for the storage of water during the night, when the load is light, will still be possible for use during the next day when the load is heavy.

In backing up this water, the amount of which can of course be regulated as will be seen from the description of the dam construction below, in the ultimate development, there will be formed a lake from 3 to 5 miles wide and about 40 miles long, overflowing the lowlands and thereby changing the topography of the country immediately adjacent to the river. It will also submerge the Government canal mentioned above which is being supplanted by the new lock and dry dock.

DETAILS OF THE DAM CONSTRUCTION.

Resting on the solid river bottom described, the plant is being built out from the bluffs on either side almost a mile apart. The construction is handled by two distinct organizations—the Illinois division building the dam, the Iowa division the locks and dry dock. Each construction plant consists of a concrete-mixing plant, a stone-crushing plant, a central power plant supplying compressed air and

electric current to the works, a machine shop, a carpenter shop, warehouses for storing cement, warehouses for miscellaneous materials, and various other structures.

The methods of construction, if not unprecedented, may at least be interesting to such as are not familiar with hydraulic engineering work:

A cofferdam consisting of a rectangular timber crib structure, loaded with stone and made water tight by means of clay puddle, is built around a section of the dam about 1,000 feet long. The water is then pumped out of this cofferdam. In this space thus pumped dry is excavated a trench in the solid rock, on which the dam is founded. The piers and arches forming the bridge and the bottom part of the dam between these piers are then built. After this the cofferdam is removed and another section is cofferdammed and the bridge built in the same way. This continues until the bridge is extended all the way from the Illinois shore to the junction with the power house on the Iowa side. This will leave 119 large openings between the bridge piers, through which the water passes unobstructed. These openings will finally be closed off, a few at a time, by means of steel gates, and the balance of the concrete part of the dam will be placed behind these steel gates, gradually raising the crest of the dam until it has reached its full height.

The dam, including abutments, is being built 4,568 feet long, or about seven-eighths of a mile. The spillway section is 4,278 feet in length. The height above the river bed is about 32 feet and its base is 42 feet wide. The upstream face is vertical. The downstream face is an ogee curve, the upper portion a parabola over which the water will spill, the lower portion an arc of a circle which will throw the water away from the toe of the dam. On the top of the spillway are being placed the steel floodgates, one for each opening, 30 feet wide and 11 feet high, supported by concrete piers. These piers are 6 feet thick and are built integral with the dam. The piers also support an arched bridge, from which the gates will be operated by electric hoists. By manipulating these gates the water above the dam may be maintained at a nearly constant level at all seasons.

The dam is being built entirely of massive concrete without reenforcement. It is being locked into the rock bed of the river by potholes and other excavations and is practically a monolith. All concrete, except at specially isolated places, is machine mixed, carried from the mixing plant to the point of use in large buckets by trains running on the completed portion of the dam, where a cantilever crane picks up the buckets of concrete from the cars, carries them out and dumps the contents into the forms.

NEAR VIEW OF WATER FROM IOWA SHORE, MARCH 28, 1911, SHOWING COMPARATIVELY SMOOTH SURFACE OF WATER COMBINED WITH NATURAL FLOW.

BUILDING THE COFFERDAM FOR POWER-HOUSE SITE, IOWA SHORE, APRIL 5, 1911. GOVERNMENT CANAL IN FOREGROUND.

In mixing the concrete three parts of a standard grade of quartz sand, taken from the natural deposits of the Des Moines River, 2 miles south of Keokuk, is placed with one part of a standard grade of American Portland cement, and tempered with water. The stone to place with this mortar, available a few hundred feet from the end of the dam, is the run of crusher where the crusher jaws are set for standard 2½-inch broken stone. The quantities of mortar and stone are such as to produce the maximum density and specific gravity. Mass rock is used in the body of the concrete work where any minimum dimension of the finished concrete is 3 feet or over. The cubiture of such mass rock may vary from one-half cubic foot to 60 cubic feet, but all such rock deposited is thoroughly embedded in the concrete so as to form a complete union with the surrounding concrete, and stones are separated from one another in dimension by at least 12 inches. No mass rock is placed within 12 inches of any finished surface.

POWER-HOUSE STRUCTURE.

At the Iowa end of the dam, slanting downstream toward the lock, is being built the power house, 1,616 feet long and about 123 feet wide, the location of which is charted opposite page 200. The substructure is being built of massive concrete, in which are molded the water passage and water-wheel chambers. On top of this is planned the superstructure, a house of concrete brick and steel. The superstructure will contain the electric generators, transformers, and switchboards. The height of the power house from foundation to roof will be about 133 feet.

In building the power house the method is to construct a cofferdam around the entire area in which the power house is built, inclosing approximately 37 acres. The water is pumped out of this inclosure, and the work of building proceeds in the space so unwatered. In connection with the power-house construction it is necessary to excavate a large amount of rock for the foundations. The rock is blasted out with dynamite and loaded on cars by steam shovels. It is then hauled to the crushing plant and after being crushed is mixed into concrete. The concrete is hauled to the point of use in buckets and deposited in the substructure of the power house by movable steel cranes. The molds or forms for this portion of the work, involving the water passages and wheel chambers, are complicated.

The concrete used in the power-house construction complies with the specifications mentioned above in connection with the dam. Further than this, where partitions in the superstructure are less than

5 inches thick the proportion of cement and sand is 1 to 2½, respectively, instead of 1 to 3, and stone for walls of less than 10 inches thickness is screened and thoroughly separated, so that no stone in the mixture may have a greater dimension than 2½ inches.

From the power-house end of the dam, as shown on the chart opposite page 200, there will be run an ice fender for protection against logs and floating ice. This will be built upstream, curving to a junction with the shore and will be 2,800 feet long. The material will be concrete. The general design will be similar to that used by Mr. Cooper in one of the Niagara Falls developments. To the eye the fender will appear as a solid wall fencing off the power house from the river. There will, however, be large arched openings below the water level through which the water will find its way to the power house.

INSTALLATION.

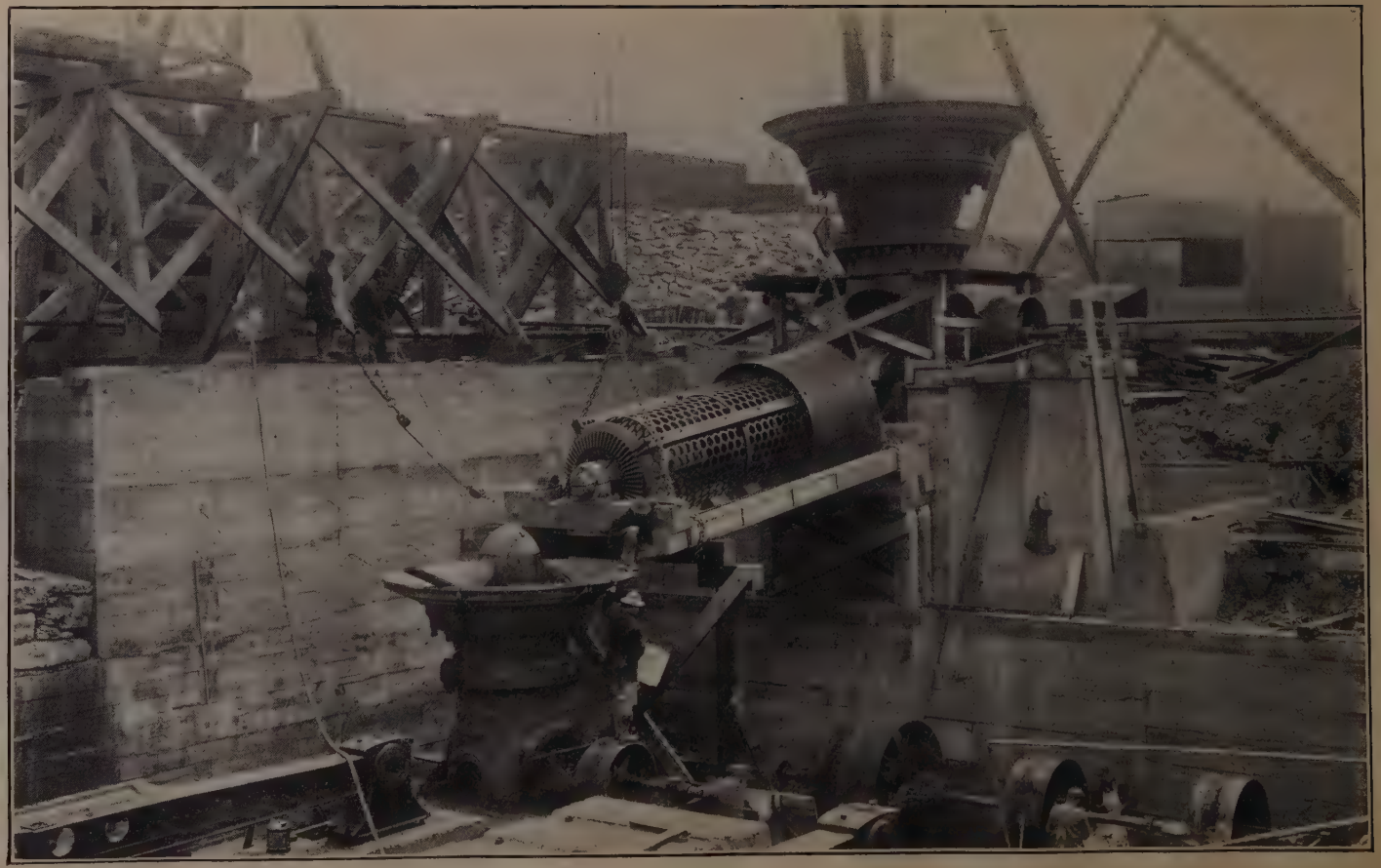
In the initial development it is planned to install 15 main water wheels of the Francis type pressure turbines with single runner mounted on vertical shaft, so providing for direct connection to main generators. These turbines are to have a normal output of 10,000 mechanical horsepower each at a speed of 57.7 revolutions per minute and head of about 32 feet. The maximum output is to be approximately 13,500 mechanical horsepower under a maximum head of about 39 feet. The design of governors, gate control, main step bearing, bucket design, and intermediate details incident thereto embody features usual in hydroelectric construction.

The main generators will likewise be 15 in number, of vertical shaft revolving field type, each having capacity of 8,000 kilowatts at normal rating with overload capacity of 25 per cent for two hours. These generators are to deliver three-phase alternating current at 11,000 volts and frequency of 25 cycles per second.

With the generators there will be installed initially two exciter turbines direct connected to the generators. These turbines will be of the same type as the main generator turbines, and will be mounted on concrete foundations and will have the same type of water inlet and discharge as provided for main units. The governors for main units and exciter turbines will be of standard construction for hydraulic regulation. Each turbine will be provided with an independent governor direct connected to the turbine gate control. The exciters direct connected with the exciter turbines are to deliver direct current to the generator fields at a suitable voltage.

Initially there will be installed step-up transformers of sufficient capacity to deliver to the transmission lines, over and above the line loss 60,000 electrical horsepower which has already been contracted

CONCRETE MIXER PLANT IN OPERATION (BUILT OF CONCRETE), FEBRUARY 14, 1911.



ROCK-CRUSHING PLANT FOR CONCRETE MATERIALS, MARCH 7, 1911.

for by public service corporations of St. Louis. The transformers are to be connected up for three-phase current and to deliver current to the transmission lines at a potential of approximately 100,000 volts. Step-down transformers will be installed for delivering current at a suitable voltage for lighting the power house and operating auxiliary motors.

The transmission line to St. Louis will run from Keokuk along the east bank of the river about 155 miles to a point in the former city, and will consist of steel towers carrying two circuits, each capable of handling at least half the power specified.

For the ultimate development to be installed in the power house as above described there are planned a total of 30 turbines and generators and 4 or more exciter turbines and exciters for the generation of at least 200,000 delivered horsepower.

LOCK AND DRY DOCK.

The lock and dry dock, as indicated on the map accompanying this article, are being constructed on the west bank of the river in accordance with plans approved by the Secretary of War. These plans call for a concrete and steel lock 400 feet long from gate to gate, 110 feet wide, and capable of lowering vessels about 40 feet. The lock is to be equipped with 1 steel gate downstream, and 2 on the upstream end, the one farthest up acting as a guard for the upper lock gate. The lower gate arches upstream; the upper gates are straight. In the masonry of the side of the lock runs a culvert with laterals extending beneath the lock and valves to regulate the intake and outflow of the water. The dry dock is to be built between the lock and the bank of the river, a space roughly 463 by 140 feet inside dimensions. The walls, of course, are of concrete. A separate small hydraulic power plant will provide power for operating the lock gates and machinery connected with the lock and dry dock.

In addition to building the lock and dry dock the company has obligated itself to carry out certain improvements in channel facilities immediately below the dam and upon certain conditions to pay over to the Government a sum of money for a similar purpose.

CONCLUSION.

It is not the purpose of this paper to place upon the construction of this dam and powerful hydroelectric plant in the Mississippi Valley an industrial significance. It is, nevertheless, true that this development is placed in a region heretofore unsupplied with hydrogenerated electric power. The size of the development will enable

the furnishing of power at a comparatively reasonable price, and it is believed by inhabitants of Keokuk, of Hamilton, and the vicinity that manufacturers requiring large amounts of electric power will be attracted to the locality in the years to come. This, in a region heretofore mainly agricultural in its pursuits, can not but be quoted as an indication of one direction of economic development of this country during the next generation or so.

SAFETY PROVISIONS IN THE UNITED STATES STEEL CORPORATION.[1]

[With 11 plates.]

By David S. Beyer,

Chief Safety Inspector, American Steel and Wire Company.

At the outset it should be explained that this article is not intended to be either "popular" or "technical," in the accepted sense of these terms. If it were framed on purely technical lines it would presuppose a thorough knowledge on the part of its readers, of power generation—of machinery—of industrial organization—and would resolve itself largely into a statement of rules, specifications, methods, and appliances, that would be both uninteresting and incomprehensible to any one who did not have this knowledge. On the other hand, to explain to an outsider the mechanical construction and operation of, for instance, the different types of electric cranes, with the accidents which may occur on them—and to make clear the value of the rules and safety devices which have been worked out to prevent such accidents—might readily fill the entire space allotted to this article. The attempt will be, rather, to touch in a general way on some of the principal features of safety work in its present stage of development in the United States Steel Corporation, and to give some impression of the problems encountered, and how they are being solved in a practical way.

This work is a logical outgrowth of association with the accidents which must inevitably accompany the use of machinery. It is probably safe to say that the "casualty" or "accident" department has always preceded the "safety" department; that dealing with the men who have been injured has brought about a desire to prevent the recurrence of accidents. From the first scattering efforts in this direction have grown more systematic methods, until accident prevention has developed such a variety of detail and such breadth of possibilities, that it is fast becoming a technical branch of itself. What was originally a species of self-defense has broadened out into

[1] Copyright, 1910, by the Charity Organization Society. Reprinted by permission from The Survey: A Journal of Constructive Philanthropy, New York and Chicago. Vol. 24, No. 6, week of May 7, 1910, pp. 205–236. Some of the illustrations of the original article are here omitted.

more humanitarian lines, until at present it is being taken up on a scale that would not have been dreamed of in this country a few years ago. Safeguards once considered entirely satisfactory are being replaced by others of improved construction. New forms of protection are constantly being devised.

In some of the companies which were brought together in 1901, to form the United States Steel Corporation, organized safety departments have existed for the last 15 years; in all of them more and more attention has been given to safeguarding employees, until at present each of the main constituent companies has a corps of trained specialists who devote their time to studying the causes of accidents and to devising means to prevent them. New impetus was given this work by the interest manifested in it and the policy adopted toward it by the officials of the Steel Corporation. Every year all the men in charge of these matters for the several subsidiary companies have been called together at the general offices in New York for discussion of the problems connected with their work, the first general meeting being held in May, 1906. At these meetings the officers of the corporation have given assurances of support to the subsidiary companies in every practical undertaking for the prevention of accidents. This resulted in the formation in April, 1908, of a central committee of safety.

This committee is composed of five members representing subsidiary companies operating the largest plants and mills, with an officer of the United States Steel Corporation acting as chairman. It was empowered to appoint inspectors to examine the various plants and equipment, and submit reports of safety conditions, with suggestions for improvement. The committee was further requested to record and disseminate data on regulations, rules, devices, etc., tending toward safer working conditions in the plants.

Some idea of the breadth of the field before the new committee may be gained from the fact that it includes 143 manufacturing plants, in addition to mining and transportation properties, employing in all approximately 200,000 men.

The committee has selected as its inspectors men already engaged in safety work in the subsidiary companies. In other words the matter has resolved itself largely into a system of inter-company inspection, which gives the plants inspected the benefit of new viewpoint and varied experience, and at the same time enables the inspectors themselves to see what is being done elsewhere, and to carry back new ideas and devices to their own plants. The plan has worked well and has been of great assistance to the several companies, who hitherto had been coping with their own safety problems without definite knowledge of what other members of the great corporation family were doing.

Meetings of the committee are held about once a month, when arrangements for inspection are made, and reports considered. Drawings, photographs, rules, specifications, etc., are submitted for consideration, and such as seem desirable are sent out to all the companies. During the two years since the institution of this central committee of safety its inspectors have reported to it, in round numbers, 6,000 recommendations for increasing the safety of employees in the plants, mills, mines, and on the railroads and steamship lines of the organization. Of these recommendations 93 per cent have been adopted by the committee and carried out by the subsidiary companies. New appliances, guards for the protection of machinery, and other means for safeguarding the workmen, to the number of 100 or more each year, have been submitted for the consideration of the committee, and through the committee have been brought to the attention of and adopted by the subsidiary companies.

There has been no attempt to establish a uniform safety organization in each of these companies, since the conditions vary so greatly that this would be impracticable; the Carnegie Steel Co. has 27 different plants, the Illinois Steel Co. 6, the National Tube Co. 13, the American Sheet & Tin Plate Co. 34, the American Bridge Co. 16, the Tennessee Coal, Iron & Railroad Co. 7, and the American Steel & Wire Co. 32. In some cases the plants of a company are grouped within a radius of a few miles, in others they are located in as many as 10 or 12 States. While each company thus has its own safety organization, which has been evolved during a period of years, there are many features common to all. The following pages treat particularly of the organization and methods used in the American Steel & Wire Co., but it should be borne in mind that many of the devices and ideas found in its plants were secured from some of the other companies mentioned, through the central committee of safety and the system of inter-company inspection.

The American Steel & Wire Co. has plants in Worcester, Mass.; New Haven, Conn.; Trenton, N. J.; Pittsburg, Donora, Allentown, and Sharon, Pa.; Cleveland and Salem, Ohio; Anderson, Ind.; De Kalb, Joilet, and Waukegan, Ill.; San Francisco, Cal.; and Hamilton, Canada. Its equipment includes docks and ore-handling machinery, blast furnaces, open-hearth furnaces, Bessemer converters, blooming mills, plate mills, and rod mills; finishing departments for making nails, fence, market wire, etc., as well as specialty departments for springs, electric cables, rail bonds, wire rope, and flat wire. It unloads a boat of ore from the Michigan mines at its docks in Cleveland, reduces this to pig iron in its blast furnaces, converts the iron into steel ingots in open-hearth or Bessemer departments, rolls these ingots out into billets in a blooming mill, reduces the billets to a quarter-inch rod in the rod mills, and draws this rod down into the

wire from which your watch spring is made or your telephone connected up.

To do this there is a great variety of machinery, and the problem of bringing this equipment up to approved standards of safety and maintaining it in this condition is complicated by the widely separated locations of the plants. The logical outcome has been to place the responsibility largely in the plants themselves, with such oversight and assistance as are necessary to obtain satisfactory results. Accordingly, special inspectors have been appointed and local inspection committees organized. There are two of these committees in each mill, one of which is called the "foremen's committee," and the other the "workmen's committee."

LOCAL COMMITTEES.

The foremen's committee usually includes the assistant superintendent of the plant, the master mechanic, chief electrician, and a department foreman or two. Some of these members are retained permanently on the committee, so that they may gradually become educated to the full scope of the work. By changing one or two members at intervals, numbers of foremen receive the benefit of this experience. It is the duty of the foremen's committee to make an inspection of the plant, either semimonthly or monthly, and turn in a written report; furthermore, it goes over the recommendations of the workmen's committee, which reports weekly.

The workmen's committee is entirely distinct and is taken from the rank and file of our mill employees; for example, there may be a machinist, an electrician, and a wire drawer; or a roller, a millwright, and a carpenter, etc. These men are selected by the superintendent in consultation with the foreman from whose department they are taken, workmen of good intelligence being chosen, who will take an interest and be able to make their work count. There are from two to four men in this workmen's committee, depending on the size of the plant; they serve on the committee for a month, making one inspection a week, each inspection consuming about a day. At the end of the month an entirely new committee is appointed, and both the incoming and outgoing committees meet with the superintendent, who explains to them something of the object of their committee work. Those who have completed their term of service are told that they are to consider themselves permanently on the safety committee and to feel free at any time to mention anything which they think conducive to their own safety or that of their fellow employees. The men, pleased, of course, at the opportunity to meet the head of the plant, take considerable pride and interest in the safety work and are coming to realize more fully its importance. Several superin-

tendents state that the early members of these committees are still making suggestions, and they undoubtedly bring up many things that otherwise they would not mention at all.

The details of the committee organization are left largely to the local managers, who adapt the scheme to local conditions and bring some of their own ideas into play. One superintendent makes out the lists of workmen's committees for several months and posts them in the mill so that the men will see them and know some time ahead that they are to serve on the committee. He says that they like to see their names used in this way, and "load up" in advance for the time when they are to begin this service. At another plant it is customary to have one member of the foremen's committee go about with the workmen's committee, to explain and discuss any problems which may come up. While there are these local variations in the different plants, the plan and scope of the work are the same in all. Each committee makes a written report of its inspection, the recommendations of which are numbered, and the numbers of any incomplete item are all shown on a monthly statement until they have been carried out as mentioned later.

Our experience with these committees has been uniformly satisfactory; benefits accrue both from the actual recommendations and from the enlivened interest which the men are taking in safety appliances. A master mechanic of one of the large plants said a few days ago that he can notice a decided change in the attitude of the men toward safety matters since these committees were established; that where he used to have difficulty in keeping any safeguards in place, the men are now looking out for them and helping keep them up. Some of the things they bring to light are such as might escape an outside inspector in a dozen trips through the mill. For instance, one of the workmen's committees recently called attention to a platform which was so placed that when it rained the water deflected back into the "mixer building," where melted iron is constantly being handled. This water lying in pools on the floor would cause a serious explosion if hot metal were spilled into it. Other items refer to gear covers which have been taken off and not replaced; to steam which forms in cold weather and obscures an open reservoir; to elevator gates which have been tied up so as to make them ineffective; to places which are poorly lighted at night, etc.

MILL SAFETY INSPECTORS.

There are certain classes of equipment that require thorough inspection at frequent intervals by men of special training, who can go over them in greater detail than is possible for the mill committees. In this class are electric traveling and locomotive cranes, engine stops,

elevators, shop equipment, cars, locomotives, etc., and for them special inspectors have been appointed, who make a weekly report on a printed form. At present we have nine such forms in use. The important parts are all specified and each part is checked off on the form as the inspector goes over the cranes. One of the headings requires the man who is operating the machine to state his opinion as to its safety, and there is a provision for stopping it at once if any serious defects are found. There are at present 28 men engaged in such official inspection in the Amalgamated Steel & Wire Co.'s plants, aside from the local committees. In the larger works this takes all of one man's time, while in smaller ones two or three days or a week may be sufficient, the inspector working as a machinist, electrician, etc., the rest of the time.

The reports of foremen's committees, workmen's committees, and safety inspectors are compiled once a month and copies sent to the general offices of the company. These statements include all new items, and at the end of each report show the "Recommendations completed during current month," "Previous recommendations incomplete," "Recommendations objected to," if any, with reasons for objection. This gives a monthly survey, from which a good idea may be obtained of the general condition and progress at each plant, and additional pressure may be brought to bear where the progress is not satisfactory.

Aside from the practical value of the recommendations secured, there is a moral effect in this varied inspection which must not be overlooked. The foremen, millwrights, and repairmen—all who are in any way responsible for the condition of the machinery—are stimulated to greater care and attention in keeping everything in good shape. The knowledge that any defects will be mentioned on an inspection report (sometimes on two or three) each week until the defect has been remedied or the delay investigated, undoubtedly does much to prevent tardiness in carrying out this work. During the month of January, 1910, there were approximately 1,500 specific recommendations made by these different inspectors and inspection committees in the American Steel & Wire Co.'s plants. Of these over 500 had been entirely completed before the end of the month, with material ordered and work under way on a great many more.

BOILER PLANTS.

In mills driven by steam engines the boiler plant is the primary source of power. It generates steam which is piped to the engines, and is a storehouse of energy so great that when any mischance releases this energy in the form of an explosion buildings are demolished and lives endangered. The possibility of such catastrophes has been so emphasized by repeated boiler explosions that most States

and municipalities have laws requiring a systematic inspection of boilers by authorized inspectors. In the United States Steel Corporation this is done by an outside inspection company which makes a specialty of boiler insurance, each boiler being thoroughly inspected at least once in six months.

In addition to this inspection, which is directed mainly to the detection of corrosion or defects which might lead to an explosion, many minor arrangements can be made to contribute to the safety of men whose duties require their presence in and about boiler plants. The failure of a part in a boiler or steam pipe, insignificant in itself, can instantly involve men and machinery in a cloud of blinding vapor, so that ladders and passages that would be safe under normal conditions may bring misfortune upon the workmen groping about with ineffective vision. Under such conditions prompt and unimpeded access is needed to overhead valves and connections, stairways being preferable to vertical or inclined ladders, and all stairways, walks, tops of boilers, etc., across which it is necessary for workmen to pass should be thoroughly protected by handrails and well lighted. Plate 1 shows stairways in one of our boiler plants.

The arrangement of piping may be such as to form what is known as a "water pocket," that is, a place where water gathers from the condensation of the steam. The opening of a valve will shoot this water forward with sledge-hammer effect, bringing disaster to the piping system or the machinery to which steam is furnished, and endangering the lives of all who may be near. Water pockets should be guarded against in designing a system of steam piping, but where oversight or necessity has brought about such a form of construction the danger has been obviated by placing a "drip" in the water pocket, that is, a small drain with a valve through which the objectionable water may be allowed to flow from the pipe before a main valve is opened.

Many plants are provided with a tunnel underneath the boilers, through which, where coal fuel is used, the ashes are removed; not infrequently these tunnels are so arranged that there is a "dead end," from which there is no means of egress. A break which would let steam or hot water flow into the tunnel and cut off escape by the one outlet provided would be liable to scald or suffocate any workman who happened to be in this section of the tunnel. Six cases of tunnels with "dead ends," which have come under our observation in the past two years, have been corrected by providing additional doors, ladders, or other outlets.

Every boiler is equipped with a gauge glass, that is a vertical glass tube about three-quarters of an inch in diameter, by which the height of the water in the boiler can be known. These glasses frequently break, as they are subjected to the same steam pressure as the boiler

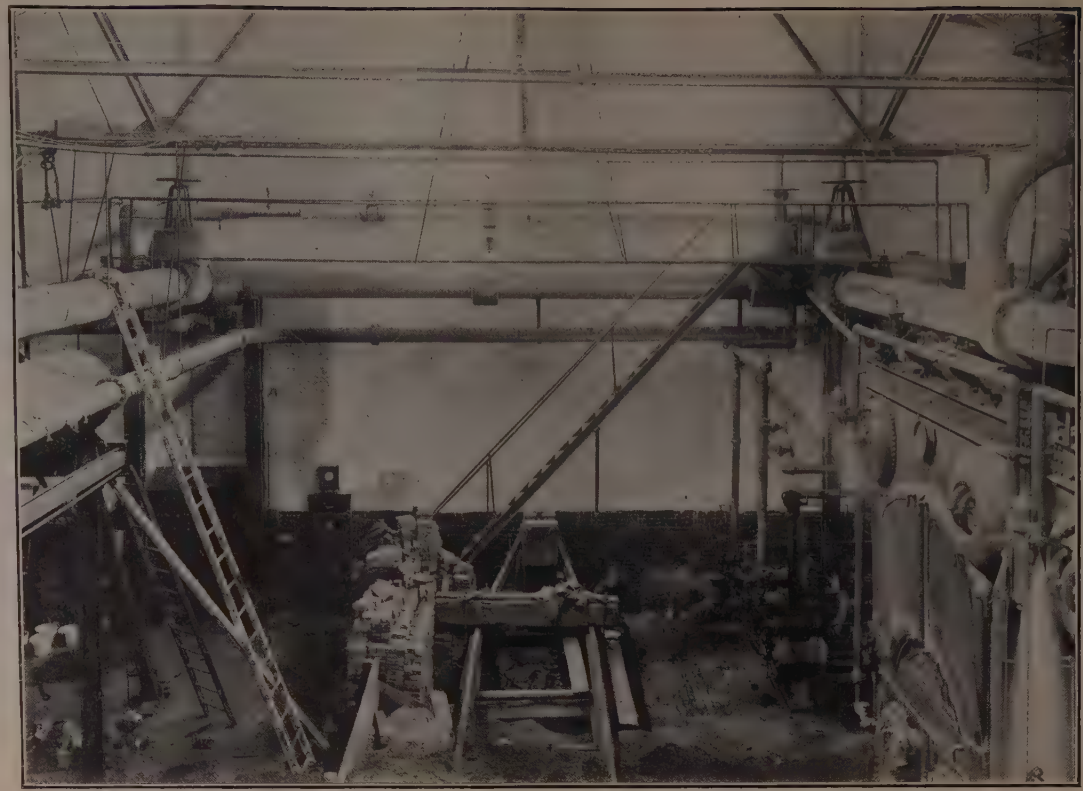
itself, which may be from 100 to 150 pounds per square inch, with a temperature of from 300° to 350° F. When a boiler tender opens the valve after putting in a new glass it is liable to explode before his face like the cannon cracker which the boy celebrating the Fourth of July holds too long after lighting, and the results are much the same—more or less severe cuts and burns, and possible destruction of his sight. Danger from this source has been eliminated by using the gauge-glass guard shown in plate 2, figures 1 and 2. This guard is made of sheet steel, and can be turned in front of the glass when anyone is working about it. After the work is done it is swung around back of the glass, so as not to interfere with the view of the water.

A number of our boiler plants have been equipped with nonreturn valves, which only come into play in case of an accident. There may be 10,000 horsepower of boilers connected into one piping system, so that if any part of a boiler or main steam pipe fails this stored-up energy will be released with terrific force at the point where the break occurs, until valves can be closed or fires drawn and the boilers cooled down. The nonreturn valve closes automatically in case of accidents of this sort, and thus brings the system under control without the risk which must be taken by men going in to close the valves by hand.

Three connections are necessary for each boiler—one through which water to be evaporated is admitted; a connection from the boiler to the main piping through which the steam is carried away, and a connection to a system of "blow-off" piping, so that the sediment which settles from the water can be blown out at intervals. Entrance to a boiler is obtained by means of a "manhole," which is just about large enough to enable an average-sized man to wriggle through comfortably—a process which can not be accomplished very quickly. Thus the workman who enters a boiler while other boilers of the same plant are in use is necessarily at the mercy of the men outside, as the accidental opening of a valve might result in his serious scalding. There are long rows of these valves exactly alike, and mistakes are liable to occur. To guard against this the valves have been numbered and red warning signs marked "Danger—do not move" are hung on them when anyone is in a boiler. Wherever practicable it is made the duty of the man doing the work to place these warning signs.

ENGINE INSTALLATIONS.

The power which turns the shafting and drives the machinery in our mills, is furnished chiefly by large steam engines. These engines have flywheels weighing from 25 to 75 tons each, running at a rim speed of 5,000 or 6,000 feet per minute. The energy stored in one of these wheels when operating is about equivalent to an average sized



STAIRWAY FOR REACHING OVERHEAD VALVES AND PIPING IN BOILER HOUSE.

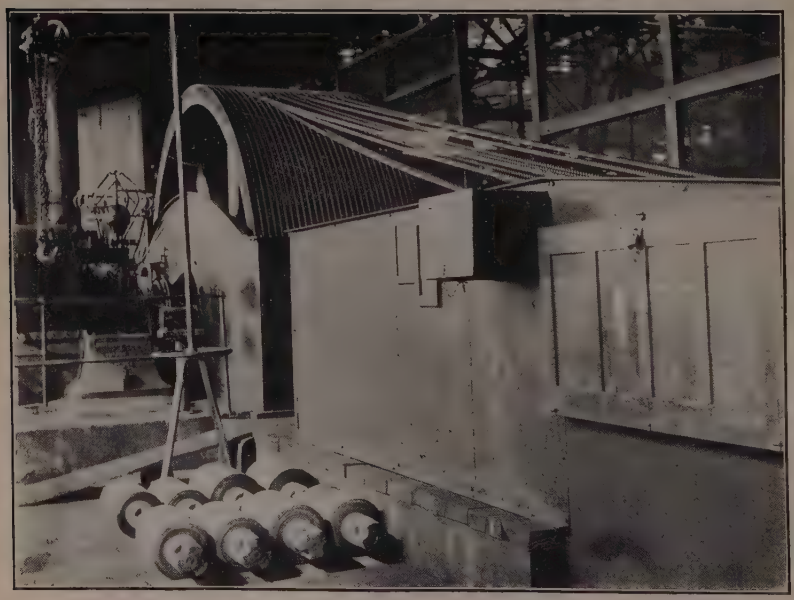
The old method of doing this is indicated by the ladders on the left.

ANOTHER VIEW OF THE SAME STAIRWAY, SHOWING OVERHEAD CROSS WALK OF STEEL GRATING.

This walk extends along the top of the boilers and gives access to each of the

1. GAUGE GLASS FOR INDICATING HEIGHT OF WATER IN A BOILER. SEMICIRCULAR STEEL GUARD SHOWN IN ITS NORMAL POSITION.

2. WHEN STEAM IS TURNED INTO A NEW GAUGE GLASS THE GUARD IS REVOLVED TO THE FRONT, TO PREVENT INJURY IN CASE THE GLASS SHOULD BURST.



3. VIEW OF ROPE DRIVE FOR ROD MILL, SHOWING STEEL PLATE INCLOSURE.

passenger locomotive, running at the rate of 60 miles an hour. If an engine is allowed to speed up, additional energy is imparted to the flywheel until it bursts from centrifugal force, unloosing a power which might be likened, roughly, to a locomotive and a train of several cars plowing their way through the mill at the rate of "a mile a minute." This terrific force is controlled and held in check by the "governor," which is usually an arrangement of two fly balls revolving at a speed proportionate to that of the engine, and automatically reducing or increasing the steam supply. Certain parts of the governor may break and cause the engine to "race," and if the engineer can not get a valve closed quickly enough the flywheel will "explode."

There is a safety attachment on the governor, which is intended to stop the engine in such emergencies, but engineers frequently allow this attachment to become ineffective. On a single inspection trip, this was the case with 10 out of 16 engines observed. In one instance a roll of waste was placed under the governor bracket—in another a wood block was used—in others the bolts were clamped so as to produce the same result, in two or three cases the man in charge simply said he had "forgot" to fix it up after a shutdown. One grayhaired engineer of perhaps 50 years to whom I spoke about this condition, minimized the danger, saying, "I have been running this engine now for six years and have never had an accident," and yet on further questioning he admitted that such an accident might occur at any time, due to that insignificant handful of waste, and that probably he would be the first man injured. Each of the men running these engines realized what might result from their interfering with the action of the governor, yet they all took the chance, because it never had happened in their experience.

To improve matters we are having counterweighted brackets placed under the engine governors, so that they will drop out automatically when the engine is running, without any attention from the engineer, and a written report is made weekly on one of the inspection blanks previously mentioned, which shows whether this safety feature is being used or not. As an additional safeguard, practically all the large engines in this company have been equipped with automatic stop valves having a speed limit attachment. These are intended to shut the engine down automatically when it exceeds a certain safe speed, and the valve may be closed also by pushing an electric button in various parts of the mill. At intervals here and there in the different departments there are little blue lights, each of which marks the location of a push button for the engine stop system. Sometimes they are on a column, sometimes suspended over a machine, and there are anywhere from five or six up to forty or fifty of them in each system. If a man is caught in the machinery, or there is a breakdown of any

sort, one of these buttons is pushed, which shuts off the steam and stops the engine. Nearly one hundred of these stops have been installed in plants of the American Steel & Wire Co.

The push buttons operate by electricity—and the small wires which carry the current to the engine-room may be broken, the push buttons may be get out of order, or the batteries develop defects; here, if anywhere, "eternal vigilance" is the price of safety, and we have arranged that the daily shutting down of the engines shall be by means of these buttons, and that once a week each button shall be pushed with a man at the engine throttle to see that it works properly—the speed limit tried, the voltage of the batteries taken, and the lines tested for breaks; all of this being reported on a printed form. In several places butter-fly valves have been placed in steam lines to engines—that is, a valve which closes instantly by pulling a lever, and chains or wire ropes are carried from this lever to convenient points for stopping the engine from a distance.

MOTOR STOPS.

In departments driven by electricity, we have motor stops corresponding to the automatic engine stops described. In some cases these are arranged to operate by push buttons, and in others a rope is carried directly from the machinery to the switch controlling the motor, so that the switch can be pulled by means of the rope in case of emergency. Plate 3 shows a series of machines having a stop of this sort. There is an operator at each set of rolls. Recently when one of them had his hand caught he cried out, and several of his fellow operators pulled the rope with such vigor that the switch was torn bodily from the board. The motor was stopped so quickly that only the tips of the injured man's fingers went into the rolls, whereas his whole hand would undoubtedly have been crushed but for this safety stop.

ELECTRIC TRAVELING CRANES.

Electric cranes have been called the "giant laborers" of the mills. They pick up a ladle weighing 20 tons, with 50 tons more of molten iron inside it, carry, and pour it as readily as if it were a cup of tea. Heavy rolls and housings used in the mills are lifted out and replaced by them, and in many departments all of the daily tonnage is handled one or more times by cranes. They are excellent servants, but sometimes they blunder, and a ladle of steel upset may mean disaster to a dozen men. There are gears and wheels which mangle; and 20, 30, 40 feet of space underneath the man who falls from a crane bridge.

Some one has said that the education of a child should begin with its grandparents; certainly the best time to safeguard a crane is before it is bought. This method can be used when new machinery

is being obtained, and in order to insure proper attention to these matters by crane builders, standard safety specifications have been prepared for use in ordering new equipment for the American Steel & Wire Co. These specifications provide for a footwalk on the side of the crane bridge, with a toe board along the edge of this walk; exposed gears are to be covered and overhung gears eliminated. (Examples of these conditions are shown in pl. 4, figs. 1, 2); limit switches are required to prevent a load being lifted too high and breaking away from the drum; a safety switch is to be placed on the upper part of the bridge so that a workman can throw out this switch and prevent anyone starting the crane from the cab while he is at work; safety couplings, brakes, and bumpers are specified; also a gong which the operator can ring to warn anyone underneath of the approach of the crane; a brush or prong is required which moves along the track in front of the crane wheel, and would push aside a hand or foot resting on the rail of the runway before it would be crushed by the wheel. Wire ropes are also specified for hoisting purposes instead of the chains which have been used largely in the past; the failure of a single link in a chain means dropping the load, while several members of a wire rope may be broken without interfering with its service, and the broken strands give warning of weakness which would not be apparent in a chain.

One of the most important safety provisions for a crane is a footwalk on the bridge (see pl. 4, fig. 1), for the use of the crane operator, who must go all over his crane every day or two to oil and inspect it, and for the repairmen, who must handle tools and remove and replace parts of the crane. Where a footwalk is not provided, it is necessary to walk on the upper edge of the girder, the surface of which is bisected by a rail and broken up by rivets and bolts, and is, moreover, frequently slippery with grease or oil which drips from the bearings. If mention is made at the time the order is placed, any of the standard crane builders will furnish a footwalk on the crane; but of course it adds slightly to the cost, and in view of the competitive bids on such work, it is only natural that the footwalk should be omitted if it is not distinctly specified.

Where these general matters have not been considered in designing and arranging the different parts of a crane, it is difficult, and sometimes impossible, for an operating company to make all of the above safety provisions, but whenever practicable they are being installed on our old equipment.

FOR WIRE DRAWING EQUIPMENT.

Plate 5 shows the arrangement of a modern wire mill. A coil of rods or wire is placed on a reel, from which it is drawn through a die to a revolving block, the opening in the die being smaller than

the original wire, so as to decrease its diameter. It is possible by this process of cold drawing to reduce a quarter-inch rod to the thickness of a hair—that is, one or two thousandths of an inch.

There are several things which may occur to endanger the wire drawer: If the wire does not uncoil freely the reel may be dragged forward and crush him against the frame of the machine; a loop may spring over the top of the reel and catch his arm or foot, so that if the block is not stopped promptly the loop will tighten and lacerate, or even cut off the member; or the wire may break, and the flying end put out an eye or cause a scratch or puncture wound from which blood poisoning may result.

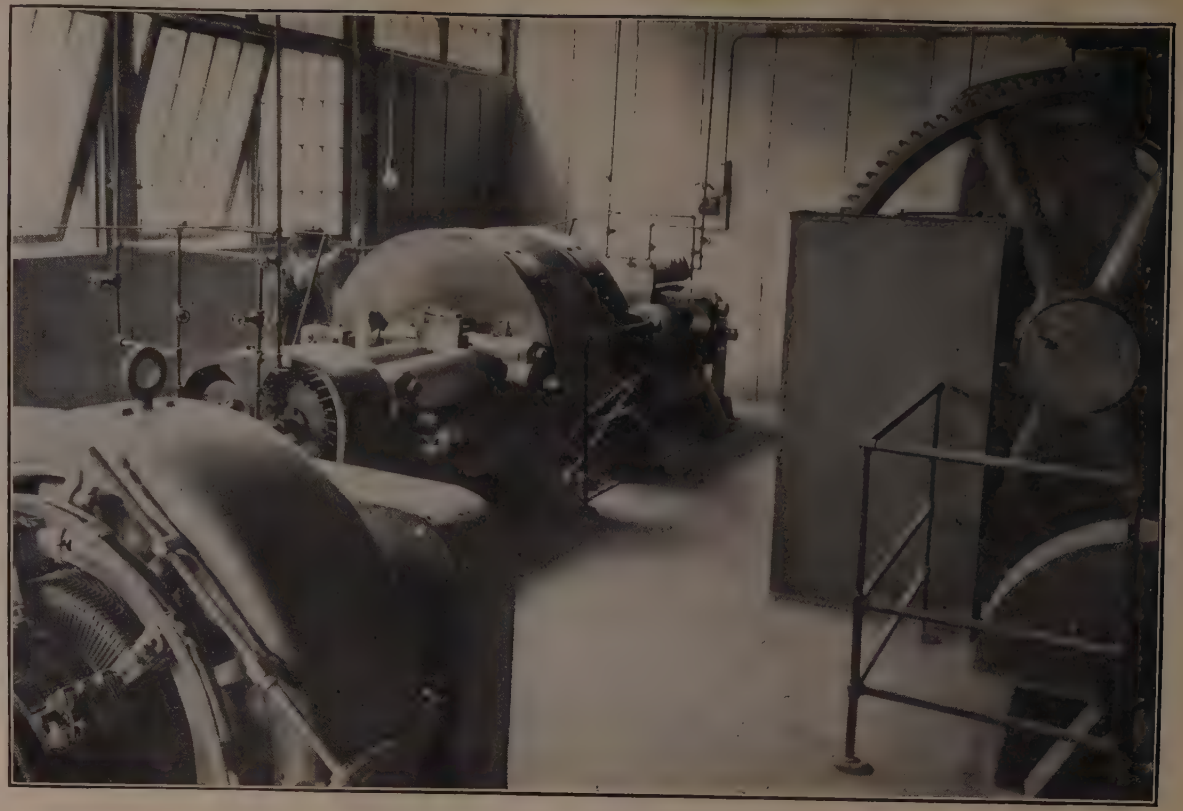
In all of our wire mills some form of a stop has been put in. A number of different applications of it were assembled on one drawing and prints sent to each plant. It is simple and effective, the only objections to it being the amount of floor space it occupies and the second's time it takes to place the wire through the lever. It may save an arm, an eye, or even a life—and yet some of the workmen have broken them off, others have refused to use them, and after a campaign of several years along this line one never goes into a mill without seeing some places where the operators carry the wire past the safety lever without using it.

MISCELLANEOUS SAFETY PROVISIONS.

In addition to the more common forms of protection, such as the elimination of projecting set screws, covering of gears (pl. 6), erecting of railings, etc., there are a great many provisions which could not be described in detail in an article of this sort. One of the dangerous occupations in the mill is that of oiling shafting and machinery. Wherever practicable, arrangements have been made to do this while the equipment is not in operation; in some cases oil cans are used, having light spouts 10 or 12 feet long, which enable a man to oil overhead shafting without leaving the floor; in other cases railed walks have been erected along lines of shafting, so that the bearings may be reached without unnecessary risk or inconvenience.

Standard scaffolds with handrails are provided for the use of painters, riggers, etc., and a "painter's chair" has been designed which has a safety belt, so that if a man were to fall out of the seat the belt would still hold him. Rules regarding the construction, inspection, and testing of this equipment have been posted in all of the shops where such appliances are used.

Counterweights are being boxed so that they can not fall on anyone in case a rope or chain breaks; covers and shields are provided for emery grinders (pl. 7); safety stops of various kinds are arranged to enable machines to be shut down quickly in case anyone is caught;

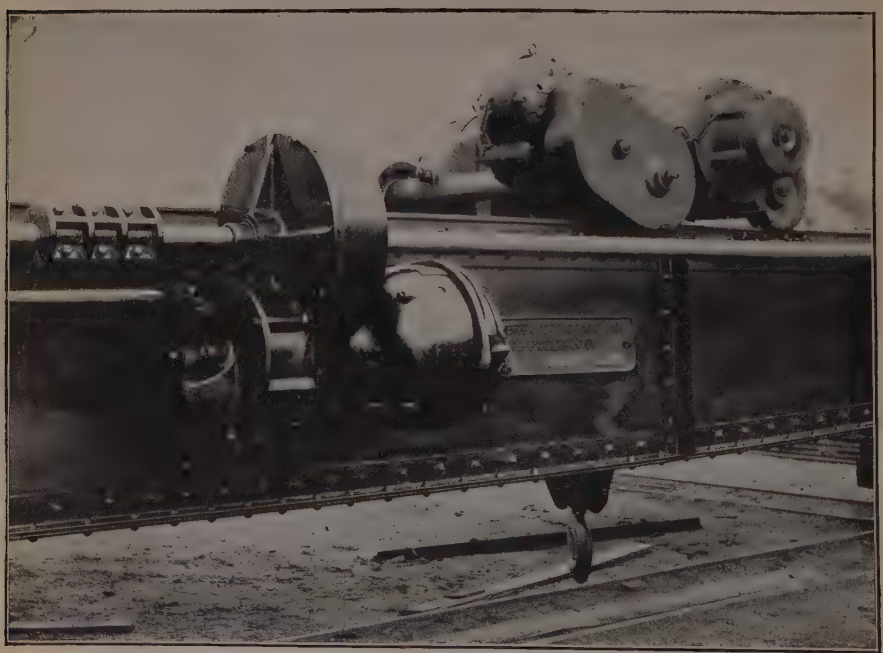


STOP ARRANGEMENT OVER ROLLING MACHINES.

By pulling the rope which the operator is holding the switch is thrown out and the motor-driving machinery is instantly stopped.

1. ELECTRIC TRAVELING CRANE BOUGHT ABOUT TEN YEARS AGO.

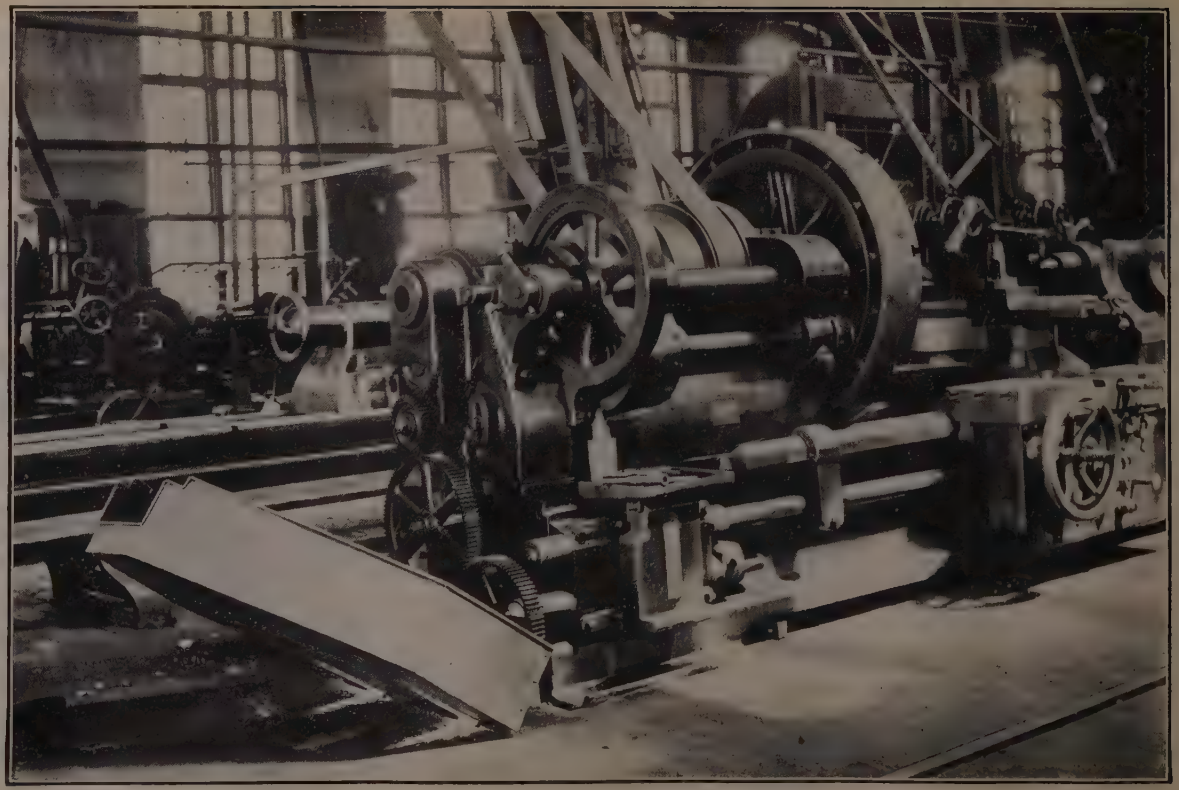
This shows open gearing, overhung gears, exposed couplings, etc. The foot walk on which the men are standing was placed on the crane after it had been installed.



2. ANOTHER CRANE VIEW, SHOWING WHAT CAN BE DONE IN THE WAY OF PROTECTING GEARS.

It is practically impossible for any one to be caught in the gearing of this crane, or for any of the parts to work loose or drop.

WIRE DRAWERS AT WORK. THE PIPES SUSPENDED OVER THE MEN ARE CONNECTED TO A CENTRAL VENTILATING SYSTEM.



A STEEL GUARD FOR THE END GEARS OF LATHES.

This can readily be swung out of the way for changing gears, and it is a good expedient for protecting gearing of a machine which was not covered by the maker.

blacksmith's tools are inspected to see that the edges are not allowed to "mushroom" until some one is struck with a flying chip; storage yards are inspected to see that material is not piled too close to the tracks; planer beds are covered in the machine shops; and safety cylinders provided for all jointers in carpenter shops.

Accidents which occur are studied with a view of determining means for preventing similar accidents, and a constant effort is made to anticipate danger in any form before it results in an accident.

General specifications, rules, drawings, and photographs of standard appliances are being compiled in a handbook, which it is intended shall be to the safety inspector what the standard reference books are to the engineer; these handbooks will be furnished to those who are responsible for the design, installation, and maintenance of equipment in our mills.

NEW PLANTS.

In erecting a new plant or in making extensions to an old one, much of the machinery is bought in practically completed form from outside manufacturers. When gear covers, etc., have to be adapted to old machines the results are always more or less unsatisfactory; the arrangement may be such as to afford no adequate means for attaching a guard, or a cover which protects one part of the machine may interfere with some of the other working parts. These difficulties can all be avoided if sufficient thought and attention are given to safety considerations when new machinery is being designed, as the different parts can then be arranged most advantageously. In planning a new plant, the drawings are all checked over to see that the latest safety provisions have been included; the following note was inserted in a contract prepared recently for a mill to be erected by the American Steel & Wire Co.:

> Safeguarding of gears, spindles, couplings, collars, set screws, keys, etc., will be covered as fully as possible in the drawings which we furnish, but it is understood that these features shall be subject to the approval of our inspectors, who shall have free access at all times to the machinery while it is in process of construction and erection.

In addition to the detailed specifications for various classes of equipment, each of our purchasing agents has been supplied with the following stamp, with the object of further stimulating interest in safeguards on the part of machinery builders:

> Provisions for safeguarding workmen should be brought to our attention, as we will consider them in selecting new machinery and equipment.

This notice is stamped on correspondence, and the results which are already in evidence show that it is having a beneficial effect, from which other companies will profit as well as our own.

The demand for more thorough safety precautions is becoming recognized by manufacturers generally, and, when requested, most of them will furnish very good forms of protection. Plate 8 illustrates the improvement which is being made in machine tools and crane design; where open gears were the rule a few years ago, everything is now smoothly covered, and the gearing is practically invisible.

THE HUMAN ELEMENT.

From statistics which have been prepared both in this country and in Germany, it would appear that about one-third of the total number of industrial accidents are attributable in whole or in part directly to carelessness or negligence on the part of the workers themselves. In other words, a considerable percentage of the accidents which occur can be charged to the human element and can not be prevented by mechanical safeguards. If they are to be materially reduced, they require other treatment.

The problem here is largely a psychological one, and we are working on it in a number of different ways. Men are prone to take chances, and it is not surprising if the same spirit which causes one man to ignore a cold until pneumonia succeeds it, or to risk his home in the stock market, causes another to take reckless liberties with a red-hot rod. Anyone who has watched a gang of structural workers 20 stories in the air scaling the steel columns of a new building must be impressed with the needless risks that these men take.

We are endeavoring to bring about a change of sentiment among the workmen—to make them realize that it is quite as worthy and honorable to be careful and not to take such risks, as it is to assume the reckless, dare-devil attitude that is often found. There are dining rooms in practically all of our plants where the foremen assemble for lunch, with a more or less informal business meeting after the meal. Reports of accidents are discussed here, letters of instructions and general safety recommendations are taken up; talks are given; and a constant effort is made to impress upon the foremen their responsibility in warning the men in their charge, or cautioning them when they see them in any dangerous practice.

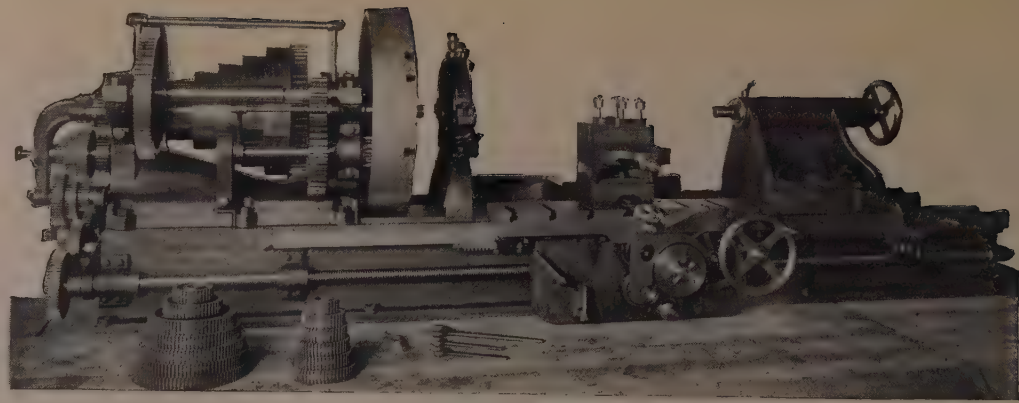
When the men receive their pay envelopes they find little "sermonettes" printed on the back of the envelopes, urging them to take care for the safety of themselves and others. These are placed also on certain printed forms which are used largely in the mills, such as the sheets on which the time distribution of the men is recorded and those on which requisitions for material are filled out. The following wordings are a few of those which have been used for this purpose;

The exercise of care to prevent accidents is a duty which you owe to yourself and your fellow employees.

Always be careful and take no risks.

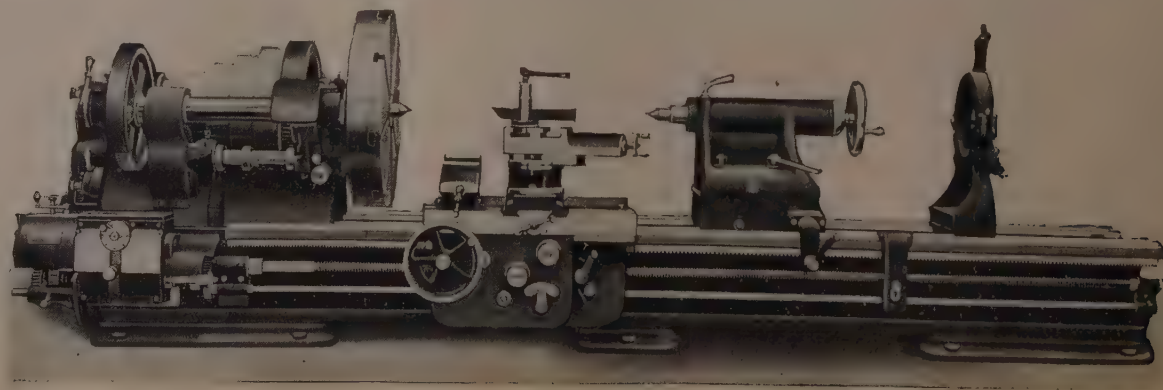
VIEW IN NAIL MILL, SHOWING SAFETY HOODS OVER EMERY GRINDERS, WHICH ARE FLANGED OUT OF A SOLID PIECE OF STEEL PLATE.

The foot treadle must be held down while the grinder is being used; as soon as the treadle is released a spring throws the overhead belt on to the "loose" pulley, stopping the grinder automatically. Walks for oilers will be noted in the trusses at the top of picture; in this case they are fenced in with boards, although pipes or structural railings are frequently used.



1. LATHE BUILT TWELVE OR FIFTEEN YEARS AGO.

A little attention has been given to protection, as the plate over the front gears shows; the remaining gears are entirely exposed.



2. LATHE OF RECENT DESIGN; THE GEARING IS SCARCELY VISIBLE.

Carelessness as to the safety of yourself or others will be sufficient cause for dismissal.

The more you insist upon carefulness on the part of others, as well as exercise it yourself, the safer it will be for all.

Report all injuries, however trivial; blood poisoning is the result of neglected wounds.[1]

Realizing that what is sometimes classed as carelessness may be merely thoughtlessness or lack of understanding, signs are posted in the mills which are intended to keep the necessity for caution fresh in the mind. Following a newspaper account of an accident in an outside company, where three men were crushed to death in the air cylinder of a blowing engine, this notice was posted in each of the blowing engine rooms of the American Steel & Wire Co.:

NOTICE.—All persons are positively forbidden to enter an air cylinder of a blowing engine until flywheels have been securely blocked, to prevent possibility of engine turning over.

——— ———, *Supt.*

Signs are placed at ladders or passageways leading to crane runways, instructing men to notify the crane operator before doing any work on a crane; warning signs are hung on valves, switches, and controlling levers of various kinds of machinery to guard against their being started while the men are working where they might be injured; notices are placed at railroad crossings and along tracks, in freight elevators, and in other places where they will attract attention to possible dangers.

Plate 8, figure 1, shows the warning sign which is used for marking electrical equipment. It is printed in six languages and is surmounted by branching lines of "red lightning," which ought to make it universally understood. The smaller sign at the top of the picture, marked "Danger—Keep away," is made of nonconducting fiber and is hung over the controlling switch to show that it should not be operated.

It is difficult to get the men to exercise the continued care which is necessary to guard against accidents. It has been said that "familiarity breeds contempt," and this is nowhere more strikingly demonstrated than in the mills.

While investigating a case recently, where the general foreman of a rod mill was injured, one of this man's assistants took me to the location in the mill where the accident had occurred, stepping over running lines of red-hot rods to reach the exact spot. He explained that a guard of wire netting had been placed at the rolls, which was supposedly fine enough in mesh to prevent a rod going through it.

[1] This is intended to encourage the men to make use of the hospital facilities described later.

By a peculiar chance, however, a rod which was exactly the same diameter as the opening in the mesh struck the screen fairly and went straight through it, injuring the man standing in front. With this catastrophe thus vividly before him, my guide started to show me another part of the mill, but instead of going round about somewhat as he might have done, he went directly along a line of guide pipes through which hot rods were running at the rate of 1,100 feet a minute. In doing so, he said apologetically, "We'd better hurry here, as a rod sometimes jumps from the pipes." If a loaded rifle were mounted in a mill and arranged to discharge at uncertain intervals, a man who passed in front of it would be considered foolish, and yet this is practically what some men are doing daily in the mills.

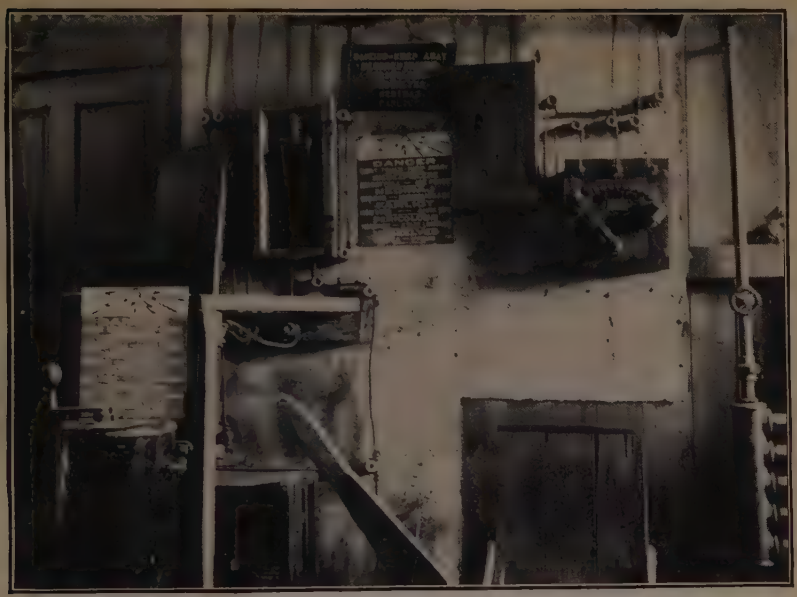
I later talked to the injured foreman and he assured me that he had been positive that the screen was fine enough to stop anything which would be rolled there and had been greatly surprised to find that the rod could get through; he saw it coming and tried to "dodge" it, but was not quick enough. As it was, he escaped very fortunately from what might have been a fatal injury. Although the hot rod practically passed through his body, penetrating a lung in its course, he was in the hospital but two weeks and was back at his regular duties in the mill four months later.

Anyone who is familiar with mill conditions, or, to put it more broadly, who knows something of human nature, realizes how difficult it is to change the accustomed method of doing things. When a safety appliance is installed it may involve some inconvenience to the workmen—it requires adjustment and repairs—at least, it is something new, and the man who has been getting along without it for several years is generally against it. If he has never seen an accident of the kind in question it seems a very remote possibility to him.

It is a slow process of education, but by continued agitation, by thorough inspection in which officials and workmen join for the common good, by commending what is good and holding it up as a model for all, the standard of safety conditions is being steadily raised.

RESULTS.

In considering the results of this work a comparison of the number of accidents occurring in the different mills shows much irregularity. A large percentage of reduction was made in some plants in 1909 as compared with the preceding year, but very little change appeared in others where an equal effort was made to improve conditions. The total number of accidents, however, is a very indefinite standard of comparison for several reasons. Slight injuries, of which no notice was taken a few years ago, are now reported; a particle of emery dust in the eye or an insignificant scratch on the hand may become infected later and develop serious complications, so that greater em-



1. MILL SWITCH BOARD, SHOWING METHOD OF MARKING ELECTRICAL EQUIPMENT.

The small sign at the top of the picture reading "Danger.—Keep away" is made of non-conducting fiber and is hung over a switch when anyone is working on the machinery it controls.

2. PROTECTIVE DEVICE FOR TRAP DOORS.

The guard rods rest on ledge of door frame when the cover is raised, and drop down out of the way when it is closed.

3. WARNING SIGN TO ATTRACT ATTENTION TO WORKMEN OVERHEAD.

Intended to prevent injury from falling tools or material.

1. WORKMEN EQUIPPED WITH SAFETY HOOD, READY TO ENTER A GASEOUS ATMOSPHERE.

This is a type of equipment which is used largely for rescue work in mines, and has been provided for our gas engine plants.

2. SAFETY HOOD, REAR VIEW.

The same air supply is breathed over and over again, being constantly purified and supplied with the necessary oxygen.

phasis is placed on having all such cases reported promptly and having proper attention given them, even though no time is lost by the man affected.

One is impressed with the capriciousness of fate when confronted with the peculiar ways in which accidents occur. An engineer had started home one evening at the end of the turn, but stopped for a moment to explain to the night man why he had been five minutes late in going on duty that morning; in doing so he placed his elbow on the end of the engine cylinder, and just at that moment the connecting rod broke and the cylinder head was knocked out, injuring him fatally. In September, 1909, there were three isolated fatal accidents in one of the Pittsburg mills, while there was none in all of the other 30 odd plants of the American Steel & Wire Co.; in the succeeding month two men met fatal injury in one of the Cleveland mills, while, as before, these were the only fatalities for the entire company.

On the other hand, there are quite as striking instances where what might have been serious catastrophes have passed off harmlessly. In one of our plants there is a group of machines in a building adjacent to the boiler plant; a couple of years ago the main belt furnishing power to these machines broke about midnight, and it was decided that it was useless to try to repair the belt that night, so the men were sent home. A little later a high wind, which was blowing, tore down the boiler stacks, and they fell over the building in which these men had been employed a short time before; parts of the wall were knocked down and a section of the roof fell in. The next morning the heavy beams and timbers which were lying over these machines indicated what might have resulted if that main belt had not snapped and the men had remained at work. Notwithstanding the fact that two buildings were wrecked, and a 16-inch steam main was broken in the boiler plant, no one was injured.

Such occurrences introduce a large element of chance, which tends to invalidate any comparison from month to month, or year to year, and the plants are being constantly extended, giving an increasing number of employees to be considered. With these varying factors it would require a detailed study and analysis of classified injuries, extending over a period of years, to give any convincing statistical information as to the decrease effected; and so far we have been concentrating on the active work of accident prevention, rather than on theoretical research of this nature.

We are very certain, however, as to the results, and numerous specific instances which might be cited give definite clues as to what is being accomplished. In one of our eastern plants, power is furnished to three floors of a wire mill by a motor located in the basement. We planned an installation of push buttons for stopping the

motor from the different floors, but had considerable difficulty in getting a safe arrangement on account of the fact that a high-voltage current was used. For several months experimental work was conducted and various devices and expedients were tried, until finally a satisfactory arrangement was secured. Shortly after the installation was completed an operator was caught on the second floor of the building and was drawn to the block; his assistant pushed a button and stopped the machinery almost instantly, preventing any serious injury. Without the stopping device this man would probably have been killed, as it would have been necessary to go from the second floor to the basement to shut down the motor. There have been three specific instances in the last year where these motor stops have been similarly effective.

There have been several cases during the same period where accidents have occurred in places covered by recommendations of safety inspectors, before these places could be safeguarded, showing conclusively that it is possible to anticipate trouble of this sort. During an inspection tour of a plant outside the American Steel & Wire Co. the writer went over various features of the electrical installation with the chief electrician of the plant; among other points which were mentioned was the provision of sweep brushes in front of the crane wheels, as some of the cranes had these while others did not. The electrician acknowledged the value of this device, and said that it would be placed on all cranes as promptly as possible. The day following a man had his arm cut off by one of the unprotected cranes; he was holding to the girder with his arm across the track while adjusting an electric wire and had failed to notify the crane operator that he was there. If the crane had been equipped with brushes the most serious result, regardless of his lack of ordinary precaution, would have been a fall of about six feet to a platform. Numerous instances of this sort could be cited, and while it is generally impossible to point out a particular safeguard and say it has prevented an accident, it is obvious that the thousands of protective devices which have been installed in the various plants of the company must frequently prevent injuries which would otherwise occur.

RELIEF ORGANIZATIONS.

In concluding it might be well to mention briefly the methods used by the American Steel & Wire Co. in caring for injured men and those who are incapacitated by sickness or who have reached the age limit for retirement.

There is an emergency hospital at each plant to give prompt aid to the injured; these hospitals are fully equipped with surgical instruments, dressings, beds, etc., and each is in charge of a competent

GRILL WORK PROTECTION FOR BINS AND HOPPERS.

Sometimes a workman falls through a car of coal or ore into the bin underneath the track, where he is liable to be suffocated if he can not be gotten out promptly.

surgeon paid by the company. In the larger plants, where circumstances warrant, nurses are in constant attendance. Very serious cases are sent to the public hospitals at the company's expense, and all injured men are cared for until they have fully recovered, irrespective of the manner in which their injuries were received. In cases of prolonged disability financial assistance is given to the injured man, according to the merits of the case, based on his age, family relations, and record as to term of service and faithfulness. These injury benefits are dispensed equitably without consideration as to whether the company is legally responsible for the injury or not.

In each plant there is a "mill committee," composed chiefly of foremen, whose duty it is to seek out and visit faithful employees who may have become sick and destitute. This committee investigates such cases and makes recommendations for financial relief for those whom it considers deserving. During the year 1909 more than $7,000 was distributed gratuitously in this way by the American Steel & Wire Co.

There is, in addition, a pension department, which was established in January, 1902. Pensions are granted to employees who have reached the age of 65 and who have been in the service of the company, or any of its predecessors, for 10 years; also to any who have reached the age of 55 and are physically disqualified for further service, providing they have been employed the preceding 10 consecutive years.

The following uniform method is used in computing the amount of these pensions: For each year of service, 1 per cent of the average monthly pay for the 10 years preceding retirement, is allowed; for example, a man who has been in the service of the company for 40 years, and has drawn an average of $75 a month for the last 10 years, would receive 40 per cent of $75 or $30 a month pension. Pensioners are allowed to seek employment elsewhere if they desire, and the utmost freedom of travel and residence is given them. In 1909 the American Steel & Wire Co. had 419 retired pensioners, some of them being located in England, Ireland, and Sweden, besides various parts of the United States; they receive in pensions during the year a total of $56,712. The pension fund is maintained entirely by the company, without assessment or contribution from the employees.

THE ISOLATION OF AN ION, A PRECISION MEASUREMENT OF ITS CHARGE, AND THE CORRECTION OF STOKES'S LAW.[1]

By R. A. Millikan.

INTRODUCTION.

In a preceding paper [2] a method of measuring the elementary electrical charge was presented which differed essentially from methods which had been used by earlier observers only in that all of the measurements from which the charge was deduced were made upon one individual charged carrier. This modification eliminated the chief sources of uncertainty which inhered in preceding determinations by similar methods such as those made by Sir Joseph Thomson,[3] H. A. Wilson,[4] Ehrenhaft,[5] and Broglie,[6] all of whom had deduced the elementary charge from the average behavior in electrical and gravitational fields of swarms of charged particles.

The method used in the former work consisted essentially in catching ions by C. T. R. Wilson's method on droplets of water or alcohol, in then isolating by a suitable arrangement a single one of these droplets, and measuring its speed first in a vertical electrical and gravitational field combined, then in a gravitational field alone.[7]

The sources of error or uncertainty which still inhered in the method arose from: (1) The lack of complete stagnancy in the air through which the drop moved; (2) the lack of perfect uniformity in the electrical field used; (3) the gradual evaporation of the drops, rendering it impossible to hold a given drop under observation for more than a minute, or to time the drop as it fell under gravity alone through a period of more than five or six seconds; (4) the assumption of the exact validity of Stokes's law for the drops used. The present modification of the method is not only entirely

[1] Reprinted with abridgment, by permission of the author and the American Physical Society, from The Physical Review, Ithaca, N. Y., vol. 32, No. 4, April, 1911. A preliminary account of this work was read on Apr. 23 before the American Physical Society and was published in Science, vol. 32, p. 436, September, 1910.

[2] Millikan, Phys. Rev., December, 1909, and Phil. Mag., 19, p. 209.

[3] Thomson, Phil. Mag., 46, p. 528, 1898; 48, p. 547, 1899; 5, p. 346, 1903.

[4] H. A. Wilson, Phil. Mag., 5, p. 429, 1903.

[5] Ehrenhaft, Phys. Zeit., Mai, 1909.

[6] Broglie, Le Radium, Juillet, 1909.

[7] In work reported since this paper was first presented, Ehrenhaft (Phys. Zeit., July, 1910) has adopted this vertical field arrangement so that he also now finds it possible to make all his measurements upon individual charged particles.

free from all of these limitations, but it constitutes an entirely new way of studying ionization and one which seems to be capable of yielding important results in a considerable number of directions.

With its aid it has already been found possible—

1. To catch upon a minute droplet of oil and to hold under observation for an indefinite length of time one single atmospheric ion or any desired number of such ions between 1 and 150.

2. To present direct and tangible demonstration, through the study of the behavior in electrical and gravitational fields of this oil drop, carrying its captured ions, of the correctness of the view advanced many years ago and supported by evidence from many sources that all electrical charges, however produced, are exact multiples of one definite elementary electrical charge; or, in other words, that an electrical charge, instead of being spread uniformly over the charged surface has a definite granular structure, consisting, in fact, of an exact number of specks or atoms of electricity, all precisely alike, peppered over the surface of the charged body.

3. To make an exact determination of the value of the elementary electrical charge which is free from all questionable theoretical assumptions and is limited in accuracy only by that attainable in the measurement of the coefficient of viscosity of air.

4. To observe directly the order of magnitude of the kinetic energy of agitation of a molecule, and thus to bring forward new direct and most convincing evidence of the correctness of the kinetic theory of matter.

5. To demonstrate that the great majority, if not all, of the ions of ionized air, of both positive and negative sign, carry the elementary electrical charge.

6. To show that Stokes's law for the motion of a small sphere through a resisting medium, breaks down as the diameter of the sphere becomes comparable with the mean free path of the molecules of the medium, and to determine the exact way in which it breaks down.

THE METHOD.

The only essential modification in the method consists in replacing the droplet of water or alcohol by one of oil, mercury, or some other nonvolatile substance and in introducing it into the observing space in a new way.

Figure 1 shows the apparatus used in the following experiments. By means of a commercial "atomizer"[1] A a cloud of fine droplets of

[1] The atomizer method of producing very minute but accurately spherical drops for the purpose of studying their behavior in fluid media, was first conceived and successfully carried out in January, 1908, at the Ryerson Laboratory, by Mr. J. Y. Lee, while he was engaged in a quantitative investigation of Brownian movements. His spheres were blown from Wood's metal, wax, and other like substances which solidify at ordinary temperatures. Since then the method has been almost continuously in use here, upon this and a number of other problems, and elsewhere upon similar problems.

oil is blown with the aid of dust-free air into the dust-free chamber C. One or more of the droplets of this cloud is allowed to fall through a pinhole *p* into the space between the plates M, N of a horizontal air condenser and the pinhole is then closed by means of an electromagnetically operated cover not shown in the diagram. If the pinhole is left open air currents are likely to pass through it and produce irregularities. The plates M, N are heavy, circular, ribbed brass castings 22 centimeters in diameter having surfaces which are ground so nearly to true planes that the error is nowhere more than 0.02 millimeter. These planes are held exactly 16 millimeters apart by means of three small ebonite posts *a* held firmly in place by ebonite screws. A strip of thin sheet ebonite c passes entirely around

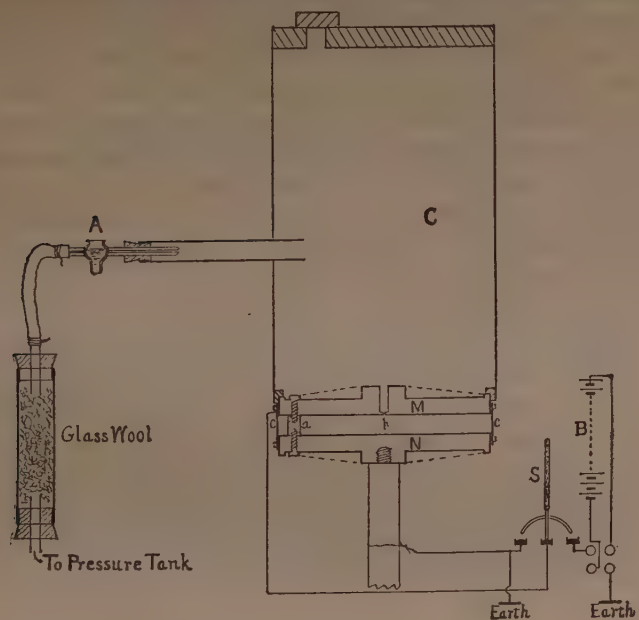


FIG. 1.

the plates, thus forming a completely enclosed air space. Three glass windows, 1.5 centimeters square, are placed in this ebonite strip at the angular positions 0°, 165°, and 180°. A narrow parallel beam of light from an arc lamp enters the condenser through the first window and emerges through the last. The other window serves for observing, with the aid of a short focus telescope placed about 2 feet distant, the illuminated oil droplet as it floats in the air between the plates. The appearance of this drop is that of a brilliant star on a black background. It falls, of course, under the action of gravity, toward the lower plate; but before it reaches it, an electrical field of strength between 3,000 volts and 8,000 volts per centimeter is created between

the plates by means of the battery B, and, if the droplet had received a frictional charge of the proper sign and strength as it was blown out through the atomizer, it is pulled up by this field against gravity, toward the upper plate. Before it strikes it the plates are short-circuited by means of the switch S and the time required by the drop to fall under gravity the distance corresponding to the space between the cross hairs of the observing telescope is accurately determined. Then the rate at which the droplet moves up under the influence of the field is measured by timing it through the same distance when the field is on. This operation is repeated and the speeds checked an indefinite number of times, or until the droplet catches an ion from among those which exist normally in air, or which have been produced in the space between the plates by any of the usual ionizing agents like radium or X rays. The fact that an ion has been caught, and the exact instant at which the event happened is signalled to the observer by the change in the speed of the droplet under the influence of the field. From the sign and magnitude of this change in speed, taken in connection with the constant speed under gravity, the sign and the exact value of the charge carried by the captured ion are determined. The error in a single observation need not exceed one-third of 1 per cent. It is from the values of the speeds observed that all of the conclusions above mentioned are directly and simply deduced.

The experiment is particularly striking when, as often happens, the droplet carries but one elementary charge and then by the capture of an ion of opposite sign is completely neutralized, so that its speed is altogether unaffected by the field. In this case the computed charge is itself the charge on the captured ion.

The measurement of the distance between the cross hairs, correct to about 0.01 mm., is made by means of a standard scale placed vertically at exactly the same distance from the telescope as the pinhole p.

THE DEDUCTION OF THE RELATIVE VALUES OF THE CHARGES CARRIED BY A GIVEN DROPLET.

The relations between the apparent mass[1] m of a drop, the charge e_n, which it carries, its speed, v_1 under gravity, and its speed v_2 under the influence of an electrical field of strength F, are given by the simple equation

$$\frac{v_1}{v_2}=\frac{mg}{\mathrm{F}e_n-mg} \text{ or } e_n=\frac{mg}{\mathrm{F}}\left(\frac{v_1+v_2}{v_1}\right). \qquad (1)$$

[1] The term "apparent mass" is used to denote the difference between the actual mass and the buoyancy of the air.

This equation involves no assumption whatever save that the speed of the drop is proportional to the force acting upon it, an assumption which is fully and accurately tested experimentally in the following work. Furthermore, equation (1) is sufficient not only for the correct determination of the relative values of all of the charges which a given drop may have through the capture of a larger or smaller number of ions, but it is also sufficient for the establishment of all of the assertions made above, except 3, 4, and 6. However, for the sake of obtaining a provisional estimate of the value of m in equation (1), and therefore of making at once a provisional determination of the absolute values of the charges carried by the drop, Stokes's law will for the present be assumed to be correct, but it is to be distinctly borne in mind that the conclusions just now under consideration are not at all dependent upon the validity of this assumption.

This law in its simplest form states that if μ is the coefficient of viscosity of a medium, x the force acting upon a spherical drop of radius a in that medium, and v the velocity with which the drop moves under the influence of the force, then

$$x = 6\pi\mu a v. \tag{2}$$

The substitution in this equation of the resulting gravitational force acting on a spherical drop of density σ in a medium of density ρ gives the usual expression for the rate of fall, according to Stokes, of a drop under gravity, viz,

$$v_1 = \frac{2}{9}\frac{ga^2}{\mu}(\sigma - \rho). \tag{3}$$

The elimination of m from (1) by means of (3), and the further relation $m = \frac{4}{3}\pi a^3(\sigma - \rho)$ gives the charge e_n in the form

$$e_n = \tfrac{4}{3}\pi\left(\frac{9\mu}{2}\right)^{\frac{3}{2}}\left(\frac{1}{g(\sigma - \rho)}\right)^{\frac{1}{2}}\frac{(v_1 + v_2)v_1^{\frac{1}{2}}}{\mathrm{F}}. \tag{4}$$

It is from this equation that the values of e_n in Tables I–XII are obtained.

PRELIMINARY OBSERVATIONS UPON THE CATCHING OF IONS BY OIL DROPS.

Table I presents the record of the observations taken upon a drop which was watched through a period of four and one-half hours as it was alternately moved up and down between the cross hairs of the observing telescope under the influence of the field F and gravity G. How completely the errors arising from evaporation, convection currents, or any sort of disturbances in the air are eliminated is shown

TABLE I.—*Negative drop.*

[Distance between cross hairs = 1.010 cm. Distance between plates = 1.600 cm. Temperature=24.6° C. Density of oil at 25° C.=0.8960. Viscosity of air at 25.2° C.= 0.0001836.]

	G sec.	F sec.	n	$e_n \times 10^{10}$	$e_1 \times 10^{10}$
	22.8	29.0	7	34.47	4.923
	22.0	21.8	8	39.45	4.931
	22.3	17.2			
G= 22.28	22.4	.....	9	44.42	4.936
V=7950	22.0	17.3			
	22.0	17.3			
	22.0	14.2	10	49.41	4.941
	22.7	21.5	8	39.45	
	22.9	11.0	12	59.12	4.927
	22.4	17.4	9	44.42	
	22.8	14.3	10	49.41	
V=7920	22.8	12.2	11	53.92	4.902
G= 22.80	22 8	12.3			
	23.0	.....			
	22.8	14.2			
F= 14.17	.....	.....	10	49.41	4.941
	22.8	14.0			
	22.8	17.0			
F= 17.13	.....	17.2	9	44.42	4.936
	22.9	17.2			
	22.8	10.9			
F= 10.73	22.8	10.9	12	59.12	4.927
	22.8	10.6			
	22.8	12.2	11	53.92	4.902
V=7900	22.8	8.7	14	68.65	4.904
G= 22.82	22.7	6.8			
F= 6.7	22.9	6.6	17	83.22	4.894
	22.8	7.2			
	.....	7.2			
	.....	7.3			
F= 7.25	.....	7.2	16	78.34	4.897
	23.0	7.4			
	.....	7.3			
	.....	7.2			
F= 8.65	22.8	8.6	14	68.65	4.904
	23.1	8.7			
	23.2	9.8	13	63.68	4.900
	.....	9.8			
F= 10.63	23.5	10.7	12	59.12	4.927
	23.4	10.6			
	23.2	9.6			
	23.0	9.6			
	23.0	9.6			
	23.2	9.5			
V=7820	23.0	9.6	13	63.68	4.900
G= 23.14	.....	9.4			
F= 9.57	22.9	9.6			
	.....	9.6			
	22.9	9.6			
	.....	10.6	12	59.12	4.927
F= 8.65	.....	8.7	14	68.65	4.904
	23.4	8.6			

TABLE I.—*Negative drop*—Continued.

	G sec.	F sec.	n	$e_n \times 10^{10}$	$e_1 \times 10^{10}$
	23.0	12.3			
$F=$ 12.25	23.3	12.2	11	53.92	4.902
	.....	12.1			
	23.2	12.4			
	Change forced with radium.				
	23.4	72.4			
$F=$ 72.10	22.9	72.4			
	23.2	72.2	5	24.60	4.920
	23.5	71.8			
	23.0	71.7			
	23.0	39.2	6		
$V=7800$	23.2	39.2			
$G=$ 23.22	.....	27.4	7	34.47	
	.....	20.7	8	39.38	4.922
	.....	26.9	7	34.47	4.923
	.....	27.2			
	23.3	39.5			
	23.3	39.2	6	29.62	4.937
$F=$ 39.20	23.4	39.0			
	23.3	39.1			
	23.2	71.8	5	24.60	4.920
	23.4	382.5	4		
	23.2	374.0			
	23.4	71.0	5	24.60	4.920
	23.8	70.6			
$V=7760$	23.4	38.5	6		
$G=$ 23.43	23.1	39.2			
	23.5	70.3			
	23.4	70.5			
	23.6	71.2	5	24.60	4.920
	23.4	71.4			
	23.6	71.0			
	23.4	71.4			
	23.5	380.6			
	23.4	384.6			
	23.2	380.0			
F= 379.6	23.4	375.4	4	19.66	4.915
	23.6	380.4			
	23.3	374.0			
	23.4	383.6			
	.....	39.2			
F= 39.18	23.5	39.2	6	29.62	4.937
V=7730	23.5	39.0			
G= 23.46	23.4	39.6			
	.....	70.8			
F= 70.65	.....	70.4	5	24.60	4.920
	.....	70.6			
	23.6	378.0	4	19.66	
	Saw it, here, at end of 305. sec.. pick up two negatives.				
	23.6	39.4	6	29.62	4.937
	23.6	70.8	5	24.60	4.920

Mean of all e_1s=4.917

DIFFERENCES.

24.60—19.66=4.94
29.62—24.60=5.02
34.47—29.62=4.85
39.38—34.47=4.91

Mean dif.=4.93

by the constancy during all this time in the value of the velocity under gravity. This constancy was not attained without a considerable amount of experimenting. It is sufficient here to state that the heating effects of the illuminating arc were eliminated, first by filtering the light through about 2 feet of water, and, second, by shutting off the light from the arc altogether except at occasional instants, when the shutter was opened to see that the star was in place or to make an observation of the instant of its transit across a cross hair. Further evidence of the complete stagnancy of the air is furnished by the fact that for an hour or more at a time the drop would not drift more than 2 or 3 millimeters to one side or the other of the point at which it entered the field.

The observations in Table I are far less accurate than many of those which follow, the timing being done in this case with a stop watch, while many of the later timings were taken with a chronograph. Nevertheless this series is presented because of the unusual length of time over which the drop was observed and because of the rather unusual variety of phenomena which it presents.

The column headed G shows the successive times in seconds taken by the droplet to fall, under gravity, the distance between the cross hairs. It will be seen that, in the course of the four and one-half hours, the value of this time increases very slightly, thereby showing that the drop is very slowly evaporating. Furthermore, there are rather marked fluctuations recorded in the first 10 observations, which are probably due to the fact that, in this part of the observation, the shutter was open so much as to produce very slight convection currents.

The column headed F is the time of ascent of the drop between the cross hairs under the action of the field. The column headed e_n is the value of the charge carried by the drop as computed from (4). The column headed n gives the number by which the values of the preceding column must be divided to obtain the numbers in the last column. The numbers in the e_n column are in general averages of all the observations of the table which are designated by the same numeral in the n column. If a given observation is not included in the average in the e_n column, a blank appears opposite that observation in the last two columns. On account of the slow change in the value of G, the observations are arranged in groups and the average value of G for each group is placed opposite that group in the first column. The reading of the voltmeter, taken at

the mean time corresponding to each group, is labeled V and placed just below or just above the mean G corresponding to that group. The volts were in this case read with a 10,000-volt Braun electrometer which had been previously calibrated, but which may in these readings be in error by as much as 1 per cent, though the error in the relative values of the volts will be exceedingly slight. The PD was applied by means of a storage battery. It will be seen from the readings that the potential fell somewhat during the time of observation, the rate of fall being more rapid at first than it was later on.

MULTIPLE RELATIONS SHOWN BY THE CHARGES ON A GIVEN DROP.

Since the original drop in this case was negative, it is evident that a sudden increase in the speed due to the field—that is, a decrease in the time given in column F—means that the drop has caught a negative ion from the air, while a decrease in the speed means that it has caught a positive ion.

If attention be directed, first, to the latter part of the table, where the observations are most accurate, it will be seen that, beginning with the group for which G=23.43, the time of the drop in the field changed suddenly from 71 to 380 seconds, then back to 71, then down to 39, then up again to 71, and then up again to 380. These numbers show conclusively that the positive ion caught in the first change—i. e., from 71 to 380—carried exactly the same charge as the negative ion caught in the change from 380 to 71. Or again, that the negative ion caught in the change from 71 to 39 had exactly the same charge as the positive ion caught in the change from 39 to 71.

Furthermore, the exact value of the charge caught in each of the above cases is obtained in terms of mg from the difference in the values of e_n, given by equation (1), and if it be assumed that the value of m is approximately known through Stokes's law, then the approximately correct value of the charge on the captured ion is given by the difference between the values of e_n obtained through equation (4). The mean value of this difference obtained from all the changes in the latter half of Table I (see Differences), is 4.93×10^{-10}.

Now it will be seen from the first observation given in the table that the charge which was originally upon this drop and which was obtained, not from the ions in the air, but from the frictional process involved in blowing the spray, was 34.47×10^{-10}. This number comes within one-seventh of 1 per cent of being exactly seven times the charge on the positive, or on the negative, ion caught in the observations under consideration. In the interval between December, 1909, and May, 1910, Mr. Harvey Fletcher and myself took observations in this way upon hundreds of drops which had initial charges

varying between the limits 1 and 150, and which were upon as diverse substances as oil, mercury, and glycerine and found in every case the original charge on the drop an exact multiple of the smallest charge which we found that the drop caught from the air. The total number of changes which we have observed would be between 1,000 and 2,000, and *in not one single instance has there been any change which did not represent the advent upon the drop of one definite invariable quantity of electricity, or a very small multiple of that quantity.* These observations are the justification for assertions 1 and 2 of the introduction.

For the sake of exhibiting in another way the multiple relationship shown by the charges on a given drop the data of Table I have been rearranged in the form shown in Table II.

TABLE II.

n.	$4.917 \times n$.	Observed charge.	n.	$4.917 \times n$.	Observed charge.
1	4.917	.....	10	49.17	49.41
2	9.834	.....	11	54.09	53.92
3	14.75	.....	12	59.00	59.12
4	19.66	19.66	13	63.92	63.68
5	24.59	24.60	14	68.84	68.65
6	29.50	29.62	15	73.75	.....
7	34.42	34.47	16	78.67	78.34
8	39.34	39.38	17	83.59	83.22
9	44.25	44.42	18	88.51	.....

No more exact or more consistent multiple relationship is found in the data which the chemists have amassed on combining powers, and upon which the atomic theory of matter rests, than is found in Tables I to XIII.

DIRECT OBSERVATION OF THE ENERGY OF AGITATION OF A MOLECULE.

Before discussing assertion 4 it is desirable to direct attention to three additional conclusions which can be drawn from Table I:

1. Since the time of the drop in the field varied in these observations from 380 to 6.7 seconds, it will be seen that the resultant moving force acting upon the drop was varied in the ratio 1 to 55, without bringing to light the slightest indication of a dependence of e_1 upon the velocity. Independently of theory, therefore, we can assert that the velocity of this drop was strictly proportional to the moving force. The certainty with which this conclusion can be drawn may be seen from a consideration of the following numerical data. Although we had upon our drop all possible multiples of the unit 4.917×10^{-10} between 4 and 17, save only 15, there is not a single value of e_1 given in the table which differs by as much as 0.5 per cent from the final mean e_1. It is true that the observational error in a

few of the smaller times is as much as 1 or 2 per cent, but the observational error in the last half of the table should nowhere exceed 0.5 per cent. In no case is there here found a divergence from the final value of e_1 of more than 0.4 per cent.

2. Since the charge on the drop was multiplied more than four times without changing at all the value of G, or the apparent value of e_1, the observations prove conclusively that in the case of drops like this, the drag which the air exerts upon the drop is independent of whether the drop is charged or uncharged. In other words, the apparent viscosity of the air is not affected by the charge in the case of drops of the sort used in these experiments.

3. It will be seen from the table that in general a drop catches an ion only when the field is off. Were this not the case there would be many erratic readings in the column under F, while in all the four and one-half hours during which these experiments lasted there is but one such, and the significance of this one will presently be discussed. A moment's consideration will show why this is. When the field is on, the ions are driven with enormous speed to the plates as soon as they are formed, their velocities in the fields here used being not less than 10,000 centimeters per second. Hence an ion can not be caught when the field is on unless the molecule which is broken up into ions happens to be on the line of force running from the plates through the drop. With minute drops and relatively small ionization this condition is very unlikely to occur. When the field is off, however, the ions are retained in the space between the plates, and sooner or later one or more of them, by virtue of its energy of agitation, makes impact upon the drop and sticks to it.

These considerations lead up to assertion 4 in the introduction. It will be seen from the readings in the first half of the table that even when the drop had a negative charge of from 12 to 17 units it was not only able to catch more negative ions, but it apparently had an even larger tendency to catch the negatives than the positives. Whence, then, does a negative ion obtain an amount of energy which enables it to push itself up against the existing electrostatic repulsion and to attach itself to a drop already strongly negatively charged? It can not obtain it from the field, since the phenomenon occurs when the field is not on. It can not obtain it from any explosive process which frees the ion from the molecule at the instant of ionization, since again in this case, too, ions would be caught as well, or nearly as well, when the field is on as when it is off. *Here, then, is an absolutely direct proof that the ion must be endowed with a kinetic energy of agitation which is sufficient to push it up to the surface of the drop against the electrostatic repulsion of the charge on the drop.*

This energy may easily be computed as follows: As will appear later the radius of the drop was in this case 0.000197 centimeter. Furthermore, the value of the elementary electrical charge obtained as a mean of all of our observations is 4.891×10^{-10}. Hence the energy required to drive an ion carrying a unit charge up to the surface of a charged sphere of radius r, carrying 16 elementary charges, is

$$\frac{16e^2}{r}=\frac{16\times(4.891\times10^{-10})^2}{0.000197}=1.95\times10^{-14}\text{ ergs.}$$

Now the kinetic energy of agitation of a molecule as deduced from the value of e herewith obtained, and the kinetic theory equation, $p=\frac{1}{3}nmu^2$, is 5.75×10^{-14} ergs. According to the Maxwell-Boltzmann law, which doubtless holds in gases, this should also be the kinetic energy of agitation of an ion. It will be seen that the value of this energy is approximately three times that required to push a single ion up to the surface of the drop in question. If, then, it were possible to load up a drop with negative electricity until the potential energy of its charge were about three times as great as that computed above for this drop, then the phenomenon here observed, of the catching of new negative ions by such a negatively charged drop, should not take place, save in the exceptional case in which an ion might acquire an energy of agitation considerably larger than the mean value. Now, as a matter of fact, it was regularly observed that the heavily charged drops had a very much smaller tendency to pick up new negative ions than the more lightly charged drops, and in one instance *we watched for four hours another negatively charged drop of radius 0.000658 centimeter, which carried charges varying from 126 to 150 elementary units, and which therefore had a potential energy of charge (computed as above on the assumption of uniform distribution) varying from* 4.6×10^{-14} *to* 5.47×10^{-14}, *and in all that time this drop picked up but one single negative ion, and that despite the fact that the ionization was several times more intense than in the case of the drop of Table I.* This is direct proof independent of all theory that the order of magnitude of the kinetic energy of agitation of a molecule is 5×10^{-14}, as the kinetic theory demands.

THE QUESTION OF VALENCY IN GASEOUS IONIZATION.

The correctness of assertion 5 in the case of the ionization existing in the observing chamber at the time at which the data in Table I were taken is directly proved by the readings shown in that table, since the great majority of the changes recorded in column 4 correspond to the addition or subtraction of one single elementary charge. There are, however, some changes which correspond to the addition or subtraction of two or three times this amount and which therefore seem at first sight to indicate the existence of multiply-charged ions.

The conclusion, however, that valency is exhibited in gaseous ionization is not to be so easily drawn. During the observations recorded in the first half of the table, a closed tube of radium, containing 500 milligrams of radium bromide of activity 3,000, stood about 5 feet away from the testing chamber, so that its γ rays and a portion also of its β rays could enter this chamber. At the end of the observations in the group in which G=23.14, this radium was brought up to within a few inches of the testing chamber, and six elementary charges were forced upon the drop. The radium was then taken entirely out of the room, so that the changes recorded in the last half of the table are entirely due to such ionization as exists in air under normal atmospheric conditions.

Now, so long as changes take place only when the field is off there is no way of telling whether an observed change of two units is due to the addition to the drop of a double ion or to the successive additions of two single ions. It might be possible to account, therefore, for all the multiple changes which occurred when the field was off on the theory of successive single changes. There is, however, one single change recorded in the last part of Table I, which is not to be so easily accounted for upon this hypothesis. It will be seen that the drop made one particular trip up in 378 seconds, then one down (recorded in the same horizontal line) in 23.6 seconds. Immediately thereafter it was being pulled back again under the influence of the field at the 380-second rate—a rate so slow that it could scarcely be seen to be moving at all if observed for a short time. After the lapse of 305 seconds, during which time the shutter had been opened every 30 seconds or so to see that the star was still in view it changed instantly while I was looking at it, the field being on, from the 380-second to the 39-second speed skipping entirely the 71-second speed.

This sort of a multiple change, when the field was on, has been observed a dozen or more times when the ionization was so weak that it seemed very improbable that two or three different molecules could have been simultaneously ionized in the minute tube of force having for its diameter the diameter of the drop. In fact, at the time at which the preliminary report upon this work was made it was thought that these changes constituted pretty good evidence that the ionization produced by radium does not always consist in the detachment of one single elementary charge from a neutral molecule, but consists in occasional instances, in the separation of two or three such charges from a single molecule. The method of studying ionization herewith presented is capable of furnishing a definite answer to the question here raised in the case of any particular ionizing agent. Recent work which will be reported in detail in another paper has shown that if either radium radiations or X rays of the intensities thus far used ever produce multiply-

valent ions in air, the number of such ions formed can not exceed 1 or 2 per cent of the number of univalent ions formed. At the present time therefore it seems probable that, despite the contrary evidence presented by Townsend[1] and Franck and Westphal,[2] the process of gaseous ionization by both radium and X rays always consists in the detachment from a natural molecule of one single elementary electrical charge.

MECHANISM OF THE CHANGE OF CHARGE OF A DROP.

It has been tacitly assumed thus far that the only way in which a drop can change its charge is by the capture of ions of one sign or the other from the air. When a negative charge increases there seems to be no other conceivable way by which the change can be produced. But when it decreases there is no a priori reason for thinking that the change may not be due as well to the direct loss of a portion of the charge as to the neutralization of this same amount by the capture of a charge of opposite sign. Table I shows conclusively, however, that if direct losses occur at all they take place with exceeding infrequency as compared with the frequency with which ions are captured from the air, even when there is no external source of ionization whatever. For if there were two comparable processes tending to diminish the charge (viz, direct loss and capture of opposite ions) and only one tending to increase it (viz, capture of ions of the same sign) and that one of approximately the same efficiency as one of the first two, the drop, instead of maintaining as it did in these experiments for three and one-half hours after the radium was removed from the room, essentially the same mean charge despite its repeated changes, would have quickly lost its charge and gone to the lower plate. The fact that it did not do this furnishes perhaps the most convincing evidence which has yet been brought forward that the process of evaporation, which must have been going on continuously at the surface of the drop, does not have the power of removing at all an electrical charge which resides upon an evaporating surface.[3]

There is but one more comment to be made upon Table I. At a point indicated in the table by the remark "change forced with radium," it will be noticed that the charge was suddenly changed from eleven negative units to five negative units—i. e., that six positive units were forced upon the drop. This sort of a change was one which, after the phenomenon had once been got under control, we could make at will in either direction—i. e., we could force charges

[1] J. Townsend, Proc. Roy. Soc., 80, p. 207, 1908.

[2] J. Frank u. Westphal, Verh. d. D. Phys. Ges., vol. 2, pp. 146 and 276, 1909.

[3] This question has been considerably discussed in the past and the experiments of Henderson (Phil. Mag., 50, p. 489, 1900) and at Schwalbe (Ann. de Phys., 1, p. 295, 1900) strongly support the conclusions here reached, despite the opposite evidence brought forward by Pellat (Jour. de Physique, 8, p. 225, 1899).

of either sign or in any desired number, within limits, upon a given drop. We did this as follows: When it was desired to load the drop up negatively, for example, we held it with the aid of the field fairly close to the positive plate, and placed the radium so that it would produce uniform ionization throughout the chamber. Under these conditions if the positive and negative ions were alike in both number and mobility the chance that the drop would catch a negative ion would be as many times its chance of catching a positive ion as the distance from the drop to the negative plate was times the distance from the drop to the positive plate. Similarly, if we wished to load the drop positively it was held by the field close to the negative plate. On account of the slightly greater mobility of the negative ion, and also on account of the somewhat greater numbers in which they occur, we found, in general, a greater tendency of the drops to take up negative than positive charges. In view, therefore, of the greater ease with which negative drops could be held for long intervals without being lost to the plates most of the drops studied have been of negative sign.

THE FAILURE OF STOKES'S LAW.

When the values of e_1 were computed as above for different drops, although each individual drop showed the same sort of consistency which was exhibited by the drop of Table I, the value of e_1 at first came out differently, even for drops showing the same value of the velocity under gravity. This last irregularity was practically eliminated by blowing the drops into air which was strictly dust free, but even then drops of different sizes, as determined by v_1, always gave consistently different values of e_1. This is illustrated by the observations shown in Tables III, IV, V, VI, VII, and VIII.

TABLE III.—*Negative drop No. 5.*

[Distance between cross hairs=1.303 cm. Temperature=24.6° C. Density of oil at 25.0° C.=.9041.]

	G sec.	F sec.	n	$e_n \times 10^{10}$	$e_1 \times 10^{10}$
	120.8	26.2	2	10.98	5.490
F= 11.9	121.0	11.9	4	21.98	5.495
	121.2	16.5	3	16.41	5.470
	120.1	16.3			
F= 26.40	120.2	26.4	2	.....	.....
	119.8	67.4	1	5.495	5.495
G=12007	120.1	26.6	2	10.98	.....
V= 91.50	.....	16.6			
F= 16.50	120.2	16.6	3	16.41	.....
	.....	16.5			
F= 67.73	120.1	68.0	1	5.495	.....
	119.9	67.8			
		26.4	.....	10.98	.....

v_1=.01085. Mean e_1 (weighted)=5.490.

TABLE IV.—*Negative drop No. 8.*

[Distance between cross hairs=1.033 cm. Temperature=20° C.]

	G sec.	F sec.	n	$e_n \times 10^{10}$	$e_1 \times 10^{10}$
	88.0	.....	.....	.....	.....
V=3512	88.8	95.3	2	10.98	5.490
G= 87.85	87.8	31.0	4	21.93	5.482
F= 30.9	87.4	30.8			
	87.8	47.0	3	16.41	5.470
	87.3	.....	.....	.....	.....
v_1=.01176.			Mean e_1 (weighted)=5.482		

TABLE V.—*Negative drop No. 2.*

[Distance between cross hairs=1.005 cm. Temperature=24.3° C.]

	G sec.	F sec.	n	$e_n \times 10^{10}$	$e_1 \times 10^{10}$
F= 49.15	53.8	49.2	4	21.46	5.365
	53.7	49.1			
G= 53.80	54.0	95.2	3	16.00	5.333
V=3990	——	95.5			
	53.7	96.6			
F= 95.78	53.7	95.8			
v_1=.01868			Mean e_1=5.349		

TABLE VI.—*Positive drop No. 15.*

[Distance between cross hairs=1.033 cm. Temperature=20° C.]

	G sec.	F sec.	n	$e_n \times 10^{10}$	$e_1 \times 10^{10}$
	30.4	12.8	10	52.06	5.206
	30.5	17.9	8	41.61	5.200
	30.6	43.8	5	26.08	5.216
	30.2	85.9	4	20.84	5.210
G= 30.48	30.5	85.9			
V=9010	30.7	86.4			
	30.5	85.6			
	30.7	86.2			
F= 86.09	30.5	86.2			
	——	86.4			
	30.2	2520.0	3	15.55	5.183
v_1=.04265			Mean e_1 (weighted)=5.208		

The drops shown in Tables III and IV were of almost the same size as is seen from the closeness of the values of the two velocities under gravity, and although the field strength was in one case double that in the other the values of e_1 obtained are almost iden-

tical. Similarly Tables VII and VIII are inserted to show the consistency which could be attained in determining the values of e_1 so long as the drops used were of the same size. On the other hand, the series of Tables III, V, VI, and VII, or IV, V, VI, and VIII, show conclusively that the value of e_1 obtained in this way diminishes as the velocity of the drop increases. This means of course that Stokes's law does not hold for these drops.

TABLE VII.—*Positive drop No. 16.*

[Distance between cross hairs=1.317 cm. Temperature=27.6° C.]

	G sec.	F sec.	n	$e_n \times 10^{10}$	$e_1 \times 10^{10}$
	24.61[1]	151.9			
	24.4	152.9			
F= 152.9....	24.63	152.4	5	25.75	5.150
	24.6	153.5			
	24.4	153.9			
V=9075.....	24.7	39.4	7	36.03	5.147
G= 24.57...	24.8	29.2			
	24.6	28.6			
F= 28.92...	24.50	28.9	8	41.07	5.134
	24.59	29.0			
	24.54	16.0			
	24.53	16.0	11	56.25	5.114
F= 15.93...	.....	15.8			

v_1=.05360 Mean e_1 (weighted)=5.143

TABLE VIII.—*Negative drop No. 17.*

[Distance between cross hairs=1.305 cm. Temperature=26.8° C.]

	G sec.	F sec.	n	$e_n \times 10^{10}$	$e_1 \times 10^{10}$
	23.8	31.5			
F= 31.33...	23.6	31.3	8	41.10	5.139
	23.4	31.2			
	23.7	43.8			
G= 23:58...	23.7	43.6			
V=8975.....	23.8	43.7	7	36.09	5.156
F= 43.72...	23.5	43.4			
	23.2	43.4			
F= 24.2....	23.5	24.2	9	46.29	5.144

v_1=.05534 Mean e_1 (weighted)=5.145

[1] The reading carried to hundredths of a second were taken with a chronograph, the others with a stop watch. The mean G from the chronograph readings is 24.567, that of the stop-watch readings 24.583.

In order to find in just what way this law breaks down we made an extended series of observations upon drops the velocities of which varied in the extreme case 360 fold. These velocities lay between

the limits .0013 cm. per sec. and .47 cm. per sec. Complete records of a few of these observations are given in Tables IX, X, XI, and XII.

[The reader may consult these tables in the original article, but they are here necessarily omitted for lack of space.]

The readings shown in these tables are merely samples of the sort of observations which we took on between 100 and 200 drops between December, 1909, and May, 1910. The sort of consistency which we attained after we had learned how to control the evaporation of the drops and after we had eliminated dust from the air may be seen from Table XIII which contains the final results of

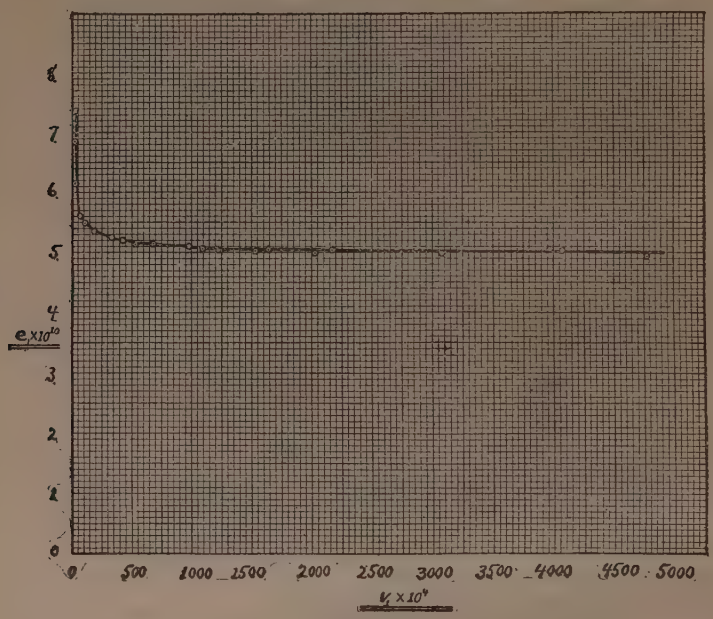


FIG. 2.

our observations upon all of the drops except three which were studied throughout a period of 47 consecutive days. The three drops which have been excluded all yielded values of e_1 from 2 to 4 per cent too low to fall upon a smooth e_1v_1 curve like that shown in figure 2 which is the graph of the results contained in Table XIII. It is probable that these three drops corresponded not to single drops, but to two drops stuck together. Since we have never in all our study observed a drop which gave a value of e_1 appreciably above the curve of figure 2, the hypothesis of binary drops to account for an occasional low value of e_1 is at least natural. Before we eliminated dust we found many drops showing these low values of e_1, but after we had eliminated it we found not more than one drop in

ten which was irregular. The drop shown in Table I is perhaps the best illustration of the case under consideration which we have observed. It yields a value of e_1 which is 4 per cent too low to fall on the curve of figure 2. This is as large a departure from this curve as we have thus far obtained.

TABLE XIII.

No.	Velocity.	Radius.	$e_1 \times 10^{10}$.	Probable error.
	cm. sec.	*cm.*		*Per cent.*
1	0.001315	0.0000313	7.384	6
2	.001673	358	6.684	4
3	.001927	386	6.142	2.5
4	.006813	755	5.605	1.5
5	.01085	967	5.490	.5
6	.01107	979	5.496	.7
7	.01164	.0001004	5.483	.4
8	.01176	1006	5.482	.4
9	.01193	1016	5.458	.8
10	.01339	1084	5.448	.5
11	.01415	1109	5.448	.4
12	.01868	1281	5.349	.5
13	.02613	1521	5.293	.5
14	.03337	1730	5.257	.5
15	.04265	1954	5.208	.5
16	.05360	2205	5.148	.4
17	.05534	2234	5.145	.5
18	.06800	2481	5.143	.7
19	.07270	2562	5.139	.5
20	.08843	2815	5.102	.3
21	.09822	2985	5.107	.4
22	.1102	3166	5.065	.4
23	.1219	3344	5.042	.5
24	.1224	3329	5.096	.5
25	.1267	3393	5.061	.5
26	.15145	3712	5.027	.5
27	.1644	3876	5.050	.3
28	.2027	4297	4.989	.7
29	.2175	4447	5.046	.4
30	.3089	5315	4.980	1
31	.3969	6047	5.060	1
32	.4074	6104	5.033	1
33	.4735	6581	4.911	1.5

THE CORRECTION OF STOKES'S LAW.

The simple form of Stokes's law, which has been used in obtaining the values of e_1 involves the assumption that there is no slip at the bounding surface between the medium and the drop, or that the coefficient of external friction between oil and air is infinite. From the standpoint of the kinetic theory this surface slip, though in general very small, is, strictly speaking, never zero, and to take it into account a term must be introduced into the equation of motion which is proportional to the ratio between the mean free path of the

gas molecule and the radius of the drop.[1] Since it is conceivable, however, that there is some other cause for slip than that assigned by the kinetic theory, it will be well to make this discussion as independent as possible of all theoretical considerations.

From whatever point of view, then, the phenomenon of external slip be regarded, it is clear that the very existence of any surface effect of this sort between the medium and the drop must tend to produce an actual velocity higher than that computed from the simple form of Stokes's law, i. e., it must tend to produce departures from Stokes's law of the kind actually shown in the experiments herewith recorded. Furthermore, it will be evident from the analysis underlying Stokes's law that any surface effect whatever between oil and air which might modify the velocity given by Stokes's law must be more and more effective in so modifying it the more the radius of the drop is diminished, and that when the radius is taken sufficiently large the term which represents this surface effect must become negligible. We could then write a corrected form of Stokes's law, which would take into account any kind of surface phenomenon which might alter the speed, in the general form

$$X=6\pi\mu av\left\{1+f\left(\frac{l}{a}\right)\right\}^{-1} \tag{5}$$

in which l is a constant of the medium and a the radius of the drop. If we were in complete ignorance of the form of the function f we could express it in terms of the undetermined constants, A, B, C, etc., thus

$$f\left(\frac{l}{a}\right)=1+A\frac{l}{a}+B\frac{l^2}{a^2}+C\frac{l^3}{a^3}, \text{ etc.} \tag{6}$$

and so long as the departures from the simple form of Stokes's law were small, we could neglect the second order terms in l/a and have therefore

$$X=6\pi\mu av\left\{1+A\frac{l}{a}\right\}^{-1} \tag{7}$$

or

$$v_1=\frac{2ga^2(\sigma-\rho)}{9\quad\mu}\left\{1+A\frac{l}{a}\right\}. \tag{8}$$

Using this form of equation to combine with (1) and denoting now by e the absolute value of the elementary charge and by e_1, as heretofore, the value of the charge obtained from the use of (4), there results at once

$$e\left(1+A\frac{l}{a}\right)^{\frac{3}{2}}=e_1 \text{ or } e^{\frac{2}{3}}\left(1+A\frac{l}{a}\right)=e_1^{\frac{2}{3}}. \tag{9}$$

[1] See O. E. Meyer, Kinetische Theorie der Gase, p. 211, for the correction of Poiseuille's law for slip, and Cunningham, Proc. Roy. Soc., 83, p. 57, 1910, for the corresponding correction of Stokes's law.

[The author then determines the value of the correcting term $\frac{Al}{a}$, and confirms his result by reference to independent work of other observers. For these discussions the reader should consult the original article.]

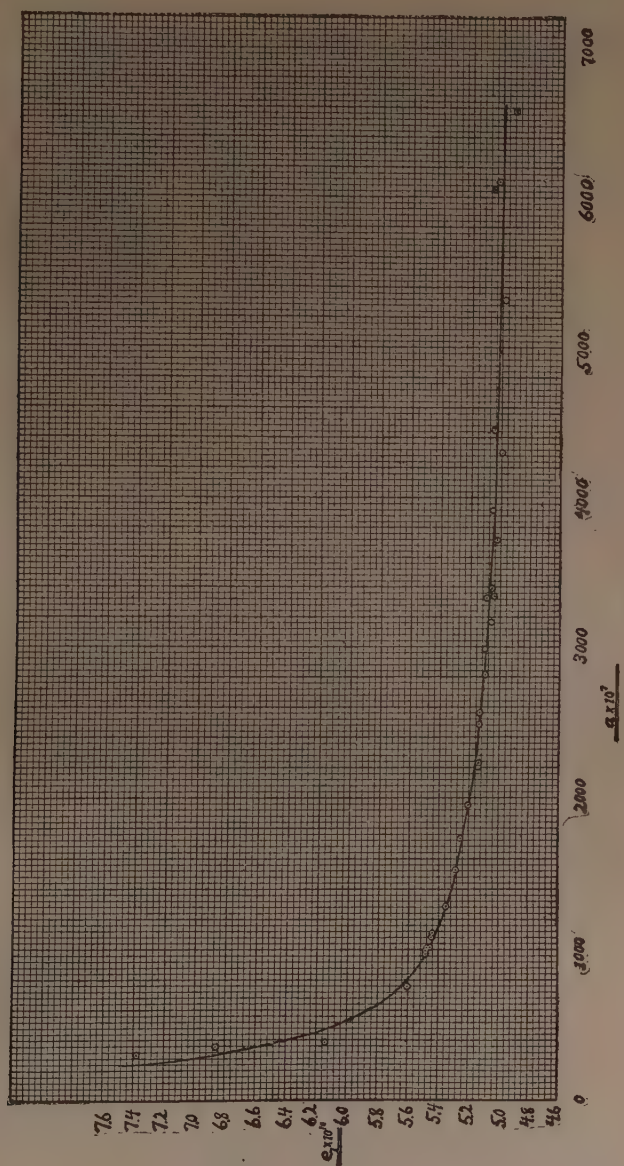


FIG. 3.

THE ABSOLUTE VALUE OF e.

Taking the value of A as 0.817 the value of e was determined from (9), and the values of e_1, a, and l obtained as explained above.

The next to the last column of Table XIV gives the results of this computation of e for all of the observations recorded in Table XIII

TABLE XIV.

No.	Temperature.	Dew point.	$l \times 10^8$.	Velocity.	a(=radius)	l/a.	$e_1 \times 10^{10}$.	Maximum observational error.	$e \times 10^{10}$.	Difference from mean.
	° C.	° C.	Cm.	Cm. sec.	Cm.			Per ct.		Per ct.
1	24.0	5.3	945	0.001315	0.0000313	0.3020	7.384	6.0		
2	26.0	10.8	954	.001673	.0000358	.2664	6.864	4.0		
3	23.8	9.3	944	.001927	.0000386	.2446	6.142	2.5		
4	19.9	1.8	929	.006813	.0000755	.1230	5.605	1.5		
5	24.6	3.7	948	.01085	.0000967	.0980	5.490	.5	4.892	0.20
6	26.4	6.0	955	.01107	.0000979	.0975	5.496	.7	4.889	.26
7	24.0	.0	945	.01164	.0001004	.0941	5.483	.4	4.903	.03
8	20.0	1.8	929	.01176	.0001006	.0923	5.482	.4	4.916	.28
9	24.8	.0	949	.01193	.0001016	.0934	5.458	.8	4.891	.22
10	26.3	6.0	955	.01339	.0001084	.0883	5.448	.5	4.908	.10
11	23.6	3.7	943	.01415	.0001109	.0850	5.448	.4	4.921	.42
12	24.3	11.0	947	.01868	.0001281	.0739	5.349	.5	4.900	.03
13	24.0	.0	945	.02613	.0001521	.0621	5.293	.5	4.910	.17
14	27.0	6.0	959	.03337	.0001730	.0554	5.257	.5	4.918	.34
15	23.2	− 1.2	942	.04265	.0001954	.0483	5.208	.5	4.913	.21
16	27.6	12.2	959	.05360	.0002205	.0435	5.143	.4	4.884	.36
17	26.8	6.0	958	.05534	.0002234	.0429	5.145	.5	4.885	.34
18	25.2	4.0	951	.06800	.0002481	.0384	5.143	.7	4.912	.21
19	23.8	5.0	944	.07270	.0002562	.0369	5.139	.5	4.913	.01
20	23.2	13.5	942	.08843	.0002815	.0325	5.102	.3	4.901	.01
21	24.6	1.7	948	.09822	.0002985	.0318	5.107	.4	4.915	.27
22	25.0	9.2	950	.1102	.0003166	.0300	5.065	.4	4.884	.36
23	27.7	15.0	959	.1219	.0003344	.0287	5.042	.5	4.882	.40
24	22.6	1.6	939	.1224	.0003329	.0282	5.096	.5	4.923	.44
25	24.0	3.7	944	.1267	.0003393	.0278	5.061	.5	4.894	.15
26	23 8	5.0	944	.15145	.0003712	.0254	5.027	.5	4.880	.44
27	25.2	.3	948	.1644	.0003876	.0245	5.050	.3	4.903	.03
28	22.3	− .7	938	.2027	.0004297	.0218	4.989	.7	4.858	.85
29	21.8	− .1	936	.2175	.0004447	.0211	5.046	.4	4.918	.36
30	22.3	4.2	938	.3089	.0005315	.0177	4.980	1.0		
31	24.4	1.0	947	.3969	.0006047	.0157	5.060	1.0		
32	22.8	1.0	940	.4074	.0006104	.0154	5.033	1.0		
33	25.2	2.7	951	.4735	.0006581	.0144	4.911	1.5		

Mean e=4.901

Six months after the original work on this table was done the laboratory obtained a very reliable Weston laboratory standard voltmeter which made it possible to obtain a more perfect calibration curve of the Kelvin and White electrostatic instrument than had been made at first. With the aid of this new calibration curve every value of e_1 in the above table was recomputed, with the result that the final value of e was reduced 0.06 per cent. Furthermore, in the computation of the above table the m of equation (1) was through oversight treated as the real mass instead of as the apparent mass. This necessitates a further reduction of e amounting to 0.14 per cent, so that the most reliable value obtainable from the work thus far done is $e=4.891 \times 10^{-10}$.

except the first four and the last four. These are omitted not because their introduction would change the final value of e, which as a mat-

ter of fact is not appreciably affected thereby, but solely because of the experimental uncertainties involved in work upon either exceedingly slow or exceedingly fast drops. When the velocities are very small residual convection currents and Brownian movements introduce errors, and when they are very large the time determination becomes unreliable, so that it is scarcely legitimate to include such observations in the final mean. However, for the sake of showing how completely formula (9) fits our experimental results throughout the whole range of the observations of Table XIII, figure 3 has been introduced. The smooth curve in this figure is computed from (7) under the assumption of $e=4.891\times10^{-10}$ and the experimentally determined values of e_1 are plotted about this curve, every observation contained in Table XIII being shown in the figure.

The probable error in the final mean value 4.891×10^{-10}, computed by least squares from the numbers in the last column, is four hundredths of 1 per cent. If there is an error of as much as 3 per cent in the determination of A the final value of e would be affected thereby by only about 0.2 per cent. Since, however, the coefficient of viscosity of air is involved in the formula, the accuracy with which e is known is limited by that which has been attained in the measurement of this constant. There is no other factor involved in this work which has not been measured with an accuracy at least as great as 0.2 per cent.

The value of μ_{15} which has been used in the computation of all of the preceding tables, viz, 0.00017856, is in my judgment the most probable value which can be obtained from a study of all of the large mass of data which has been accumulated within the past 40 years upon this constant. It represents not only the result of what seems to me to be the most reliable single determination of μ which has thus far been made, viz, that of Stokes and Tomlinson[1] who deduced it from the damping of oscillating cylinders and spheres, but it is exactly the mean of the three most recent and very concordant values obtained by the outflow method (Table XV), and it is furthermore the mean of all of the most reliable determinations which have ever been made. These determinations are as follows:

[The discussion of the determinations of the coefficient of viscosity of air is here omitted.]

We have devised two modifications of this method of determining e which do not involve the value μ. It is scarcely likely, however, that the necessary experimental error in these methods can be reduced below the error in μ It is probable, therefore, that any increased accuracy in our knowledge of e is to be looked for in increased accuracy in the determination of μ.

[1] Stokes, Math. and Phys. Papers, v. 5, p. 181.

EXPERIMENTS UPON SUBSTANCES OTHER THAN OIL.

All of the preceding experiments except those recorded in Table I were made with the use of a specially cleaned gas-engine oil of density 0.9041 at 25° C. Those in Table I were made with the use of a similar, though more volatile, mineral oil (machine oil) of density 0.8960. The reason that we worked so continuously upon a single substance was that it was found that in order to maintain a drop of constant size it was necessary, even with these very nonvolatile substances, to have the drop in equilibrium with its saturated vapor. This is shown by the following observations. The inner surfaces of the condenser plates had been covered with a very thin coat of machine oil in order that they might catch dust particles. Drops blown from a considerable number of nonvolatile substances were introduced between the plates and were found in the main to evaporate too rapidly to make accurate observing possible. This was true even of so nonvolatile substances as glycerine and castor oil, as the following observations show:

Glycerine, density 1.25.		Castor oil, density 0.975.	
G.	F.	G.	F.
28.3	11.5	73.8	18.0
32.5	9.8	75.8	12.9
38.7		77.3	18.0
45.6	8.4	78.7	102.2
59.2		79.6	17.8
		84.8	30.2
		87.7	12.7
		90.7	18.1

In order to get rid of this continuous increase in G, the drops were next blown from the least volatile liquid at hand, viz, gas-engine oil, and the behavior of a given drop showed immediately that it was growing in size instead of evaporating. This can be seen from the following readings:

Gas-engine oil.	
G.	F.
17.6	6.1
17.4	76.2
17.2	82.0
16.9	87.2
16.8	92.4
17.1	97.8
16.7	104.6
16.4	112.0

This behavior was shown consistently by all the drops experimented upon (six or eight in number) throughout a period of two days. Imagining that the vapor from the more volatile machine oil upon the plates was condensing into the less volatile but similar oil of the drop I took down the apparatus, cleaned the plates carefully, and oiled them again, this time with the gas-engine oil. Every gas-engine oil drop tried thereafter showed the sort of constancy which is seen in Tables III to XII. Series of observations similar to that made upon gas-engine oil and tabulated in Tables XIII and XIV will ultimately be made upon other substances. Thus far the aim has been to take enough observations upon other substances to make sure that the results obtained from these substances are substantially in agreement with those obtained from gas-engine oil and to concentrate attention upon an accurate series of observations upon one substance. As a matter of fact, we have a fairly complete series upon machine oil and a number of observations upon watch oil, castor oil, and glycerine, all of which are in agreement within the limits of observational error, in some cases as much as 2 or 3 per cent, with the observations upon gas-engine oil.

* * * * * * *

The conclusion to be drawn from all of the work thus far done on substances other than oil is merely that there is nothing in it to cast a doubt upon the correctness of the value of e obtained from the much more extended and much more accurate work upon gas-engine oil.

COMPARISONS WITH OTHER DETERMINATIONS.

The value of e herewith obtained is in perfect agreement with the result reached by Regener[1] in his remarkably careful and consistent work in the counting of the number of scintillations produced by the particles emitted by a known amount of polonium and measuring the total charge carried by these same particles. His final value of this charge is 9.58×10^{-10}, and upon the assumption that this is twice the elementary charge—an assumption which seems to be justified by Rutherford's experiments[2]—he finds for e 4.79×10^{-10}, with a probable error of 3 per cent. Since the difference between this value and 4.89×10^{-10} is but 2 per cent the two results obviously agree within the limits of observational error. * * *

[The author then discusses several other determinations of e, and explains some discrepancies which appear.]

In conclusion there is presented a summary of the most important of the molecular magnitudes, accurate values of which are made

[1] E. Regener, Sitz. Ber. d. k. Preuss. Acad. d. Wiss., 37, p. 948, 1909.
[2] Rutherford, Phil. Mag., 17, p. 281, 1909.

possible by an accurate determination of e. The Faraday constant is taken as $Ne = 9{,}655$ absolute electromagnetic units.

$e = 4.891 \times 10^{-10}$ E.S.U.	the smallest quantity of electricity capable of separate existence.
$N = 5.922 \times 10^{23}$	the number of molecules in one gram molecule of any substance.
$n = 2.644 \times 10^{19}$	the number of molecules in 1 cubic centimeter of any gas at 0° C. and 76 centimeters.
$\alpha = 2.106 \times 10^{-16}$ ergs.	the constant of molecular energy. Molecular energy $\epsilon = \alpha T$.
$\varepsilon_0 = 5.750 \times 10^{-14}$ ergs.	the kinetic energy of agitation of a single molecule at 0° C. and 76 centimeters. $\varepsilon_0 = 273\alpha$.
$m = 1.702 \times 10^{-24}$ gms.	the weight of the hydrogen atom.

Weights and diameters of molecules.

Substance.	Molecular weight (H=1).	Absolute weight.	Diameter.[1]	Absolute density.
		Grams.	*Centimeter.*	*G. cm.*
Hydrogen	2	3.40×10^{-24}	2.28×10^{-8}	0.55
Helium	4	6.81×10^{-24}	2.00×10^{-8}	1.63
Carbon monoxide	27.8	47.4×10^{-24}	2.89×10^{-8}	3.76
Ethylene	27.8	47.4×10^{-24}	3.40×10^{-8}	2.34
Nitrogen	27.8	47.4×10^{-24}	3.06×10^{-8}	3.17
Air	28.9	49.2×10^{-24}	2.99×10^{-8}	3.53
Nitric oxide	29.81	50.8×10^{-24}	2.69×10^{-8}	5.00
Oxygen	31.8	54.2×10^{-24}	2.89×10^{-8}	4.30
Argon	39.6	67.5×10^{-24}	2.78×10^{-8}	6.01
Carbon dioxide	43.7	74.4×10^{-24}	3.11×10^{-8}	4.73
Nitrous oxide	43.7	74.4×10^{-24}	3.48×10^{-8}	3.39
Chlorine	70.4	119.8×10^{-24}	3.01×10^{-8}	3.90
Water vapor	17.9	30.5×10^{-24}	$3(?) \times 10^{-8}$	
Ethyl chloride	64.0	108.9×10^{-24}	$4(?) \times 10^{-8}$	

My thanks are due to Profs. Crew, Carman, and Guthe for loaning to me tubes of radium when my own supply met with an accident. I wish also to acknowledge my great indebtedness to Mr. Harvey Fletcher who has most ably assisted me throughout the whole of this investigation.

[1] These diameters have been obtained from the above value of n and the viscosity equation

$$\mu = \frac{350\rho\bar{c}}{\sqrt{2}\pi n D^2},$$

Sutherland's correction for cohesional force (Phil. Mag., 17, p. 320, 1909) and Jean's correction for persistence of velocities being added. This procedure is thought to yield more reliable results than applying the above corrections to means of D obtained from viscosity, diffusion, heat conduction, and departures from Boyle's law, since computations based on the last three phenomena involve both theoretical and experimental uncertainties of large magnitude.

THE TELEGRAPHY OF PHOTOGRAPHS, WIRELESS AND BY WIRE.[1]

[With 2 plates.]

By T. Thorne Baker, Esq., F. C. S., A. I. E. E.

It frequently happens that when two alternate processes are available for certain work, and one of them is considerably less practical than the other, the less practical one is possessed of much higher scientific interest. This may certainly be said of the telegraphy of pictures and photographs. The whole of the methods of transmission can be classed as either purely mechanical, or dependent on the physical properties of some substance which, like selenium, is sensitive to light.

The latter methods are of no little scientific interest, and, although very delicate and for the moment obsolete, there is every likelihood of their coming into more extended use later on.

The telegraphy of pictures differs only from the transmission of ordinary messages in that the telegraphed signals, recorded by a marker on paper, must essentially occupy a fixed position. In the case of an ordinary telegram it matters little whether the received message occupy two, three, or more lines when written out on paper, but when a picture is telegraphed every component part of it must be recorded in a definite position on the paper.

Suppose you greatly enlarge a portrait, and divide it up by ruled lines into a thousand square parts. Suppose also that the photograph is printed on celluloid, so that it is transparent. If, now, the portrait be held in front of some even source of illumination, it will be seen that each square—each thousandth part—is of different density. The light parts of the photograph will consist of squares of little density, the dark parts, of squares of greater density, and so on. In this way the photograph is analyzed into composite sections, each section corresponding precisely to a letter in a message; letters and

[1] Lecture before the Royal Institution of Great Britain, at the weekly evening meeting, Friday, Apr. 22, 1910. His Grace the Duke of Northumberland, K.G., P.C., D.C.L., LL.D., F.R.S., president, in the chair. Reprinted by permission from author's copy published by the Royal Institution. Printed also in Nature, No. 2129, Aug. 18, 1910.

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spaces recombined form words and messages; squares of different densities recombined, in correct position, form a photograph.

I propose to deal with the more practical system first, which, as already pointed out, is perhaps the less interesting from the theoretical point of view. The telectrograph system has been employed by the Daily Mirror for the transmission of photographs since July, 1909, and has been worked very regularly between Paris and London, and Manchester and London.

Instances of its use may be recognized in the publication of photographs taken in court in the recent Steinheil case at Paris, when photographs of witnesses or prisoners were sometimes received in London actually before the court rose at which they were taken, a clear day being gained in the time of publication.

The method of telegraphing photographs that has been employed on a large scale by the Daily Mirror may be called a practical modification of several early attempts. The effect of an electric current to discolor certain suitable electrolytes or to set free an element or ion that can be used to form with a second substance a colored product was employed in many early forms of instruments for telegraphing writing, etc. If we break up a photographic image in the way already described into lines which interrupt the current for periods depending on their width, these interrupted currents can be used at the receiving station to form colored marks which join up en masse to form a new image. My telectrographic process is thus briefly as follows:

At the sending station we have a metal drum revolving under an iridium stylus, to the drum being attached a half-tone photograph printed on lead foil. Current flows through the photographic image to the line and thence to the receiver. The receiver consists of a similar revolving metal drum over which a platinum stylus traces. Every time the transmitter style comes in contact with a clear part of the metal foil current flows to the receiver, and a black or colored dot or mark appears on the chemical paper. But you will readily understand that if our reproduction—built up of these little marks, which have to be made at the rate of some 200 per second—is to be accurate, each mark must be only exactly as long, in proportion, as the clear metal space traversed by the stylus.

It will be easier to explain the system by means of the rough diagram shown in figure 1. The transmitting instrument is shown on the left, the receiver on the right. A metal drum is revolved by a motor, one revolution every two seconds; over this a metal stylus or needle traces a spiral path in the same way as a phonograph. On the drum is fixed a half-tone photograph broken up into lines, and printed in fish glue upon a sheet of lead foil. I will show one of these line photographs on the screen, and you will see that the light

and shade of the picture is made up of masses of thinner or thicker lines, with clear spaces in between.

As the stylus traces over such a photograph, its contact with the metal base is interrupted every time one of these fish-glue lines comes beneath it, and for such a time as depends, of course, on the *width* of the line. The transmitting instrument thus sends into the telegraph lines a series of electric currents whose periods of duration are determined by the width of the lines composing the photograph.

A similar stylus, S_2, traces an exactly similar path over a revolving drum in the receiving instrument, but round this drum is wrapped a piece of absorbent paper impregnated with a colorless solution, which turns black or brown when decomposed by an electric current.

What happens then is that every brief current which passes through the paper causes a mark to appear on it. The width of the mark depends on the duration of the current—or should so do—so that

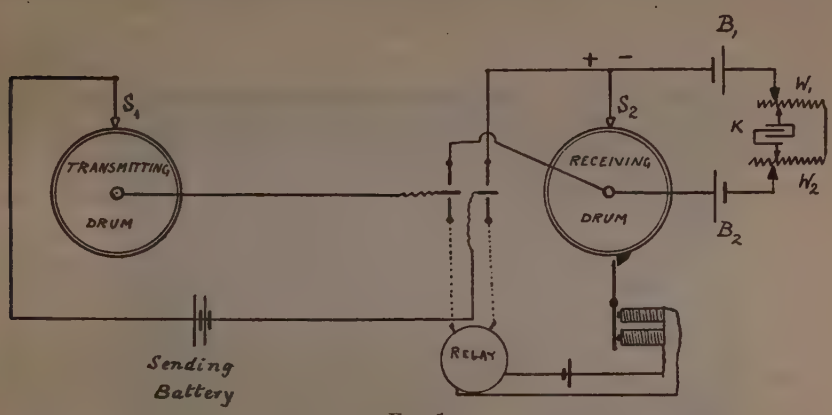


FIG. 1.

you will see that these marks gradually combine to recompose the photographic image.

This method is all very well in the laboratory, but when we come to try it over a long distance the capacity of the line at once causes serious interference. It is well known that if a current be sent to some apparatus, such as a telegraph, from a distance, the current having to pass through long wires the capacity of which is appreciable, a certain time is taken for the current to charge the line, and the line discharges itself into the apparatus with comparative slowness. If the circuit be closed by means of a Morse key, the time of contact at the key being a sixth of a second—a common time of duration of a short tap—the discharge of current from the cable would be considerably longer than one-sixth of a second. When, therefore, we are sending signals through the line at the rate of 175 per second, it is not difficult to see that every signal will run into the next dozen

or so at the receiving apparatus, and the result will be a hopelessly confused mass of overlapping marks. This is well illustrated in plate 1, figure 1, where A shows a series of taps passed through a cable of high capacity into the telectrograph receiver; instead of getting a series of sharp dots or short lines, we get elongated lines ending off in tails. Without the capacity, we get the short lines as shown in the B series. These short, definite lines are again obtained, even when the capacity is present, in series C; but in this case I had shunted on to the receiver what I have termed the line balancer, a modified form of shunt apparatus embodying the principles of wiping out residuary currents from the cable in the way frequently made use of in duplex telegraphy.

The use of this apparatus has rendered commercial the old ideas of telegraphing by the electrolytic method, and as many as 300 sharply defined chemical marks can be recorded in one second by its means. The method of application will be seen if we have the last slide shown again (fig. 1); here, shunted on to the line (which is closed by the stylus S_2 and the metal drum), is a circuit containing two batteries, B_1 and B_2, and the two sections of a divided 1,000-ohms resistance, W_1 and W_2. Shunted across the variable contacts of the resistances is a variable condenser K. By varying the resistances, W_1 and W_2, we can vary the power of the current used to sweep out the residuary charges in the line; the current can, of course, flow through the chemical paper on the drum, but the pole of the battery B_1, connected to the style, is of opposite sign to that of the line unit connected to it.

When the leakance on the line is great and evenly distributed, less reverse current from the balancer is necessary, this being quite in accordance with Heaviside's formulæ for telephony over lines with capacity and inductance. It is interesting to note, also, that by increasing the voltage of the reverse batteries B_1 and B_2, considerably greater contrast can be obtained in the pictures; the finer the halftone screen employed in splitting up the photographs into lines, the higher, again, must the voltage of B_1 and B_2 be made.

I should like to take up a few moments in referring to the actual utility of phototelegraphy. The demand by the public for illustrations in their daily papers must be admitted. News is telegraphed in order to expedite its publication, and photographs illustrating this news can therefore be telegraphed advantageously. But where a large installation and establishment, with accumulators, a large instrument, and an operator to work it are required, the cost of telegraphing every individual picture becomes quite out of proportion to its value. It is therefore desirable to direct special attention to the portable instruments, the first one of which is shown for the first time to-night. A photographer going to obtain pictures of some

1.

2. PHOTOGRAPH SHOWING A PORTION OF THE PHOTO-TELEGRAPHIC APPARATUS.

important function or interesting event can take the machine with him, prepare his pictures, and telegraph them to his head office, and when the event is over he simply returns with the apparatus. For criminal investigations, the portable instrument will, I feel sure, become of considerable value also. Through the continued courtesy shown by the Postmaster General and Maj. O'Meara, the engineer in chief, we have been given every facility for developing the work, and I believe that the uses of the portable instrument will before long have been amply demonstrated.

If a picture revolving beneath a tracer has to redraw itself, as it were, on a piece of paper perhaps hundreds of miles away, it is obvious that each mark redrawn must occupy a precisely similar spot on the new paper as it does in the original picture. As cylinders or drums are used in picture telegraphy, this means that they must revolve in perfect unison. If one drum were to gain on the other we should have, in the case of a portrait, a nose being recorded where the eye ought to be, or something equally disastrous; in fact, if the two machines get the least bit out of step, the received picture is completely ruined. The method of synchronising used by Prof. Korn has proved very satisfactory, and has been adopted in practically all systems of phototelegraphy. The motors which drive each drum are run at about 3,000 revolutions per minute, and geared down very considerably, so that the drums themselves revolve, perhaps, at 30 revolutions per minute; the motors are run from secondary batteries of ample capacity to insure smooth working, and should be run for a sufficient time before beginning a transmission to allow of their warming up.

The speed of each motor is controlled by a regulating resistance in series with the field magnets, and the speed is ascertained by means of a frequency meter, which indicates the number of revolutions per second. The dial of this meter is shown on the screen. A set of tuned steel tongues are fixed in front of a magnet, which is supplied with alternating current obtained from slip rings on the motor, and each tongue has a different period of vibration. When the alternations in magnetism correspond with the period of vibration of any one spring, that spring vibrates, and thus serves as an indication of the speed of the motor.

The receiving drum is revolved a little quicker than the transmitting drum. It consequently completes its revolution before the transmitter. It is then stopped by a steel check, and is obliged to wait until the other drum has caught it up. When the transmitting drum has completed its turn, a fleeting contact comes into play, a reverse current is sent to the receiving instrument; this is led into a polarized relay, which actuates an electromagnet, and this magnet removes the check.

Thus, however much one drum gets out of step with the other, the fault is limited to each revolution, and both drums must always start off in unison for each new revolution. I have found that where each operator endeavors to keep his motor running uniformly by regulating the resistance according to the fluctuations recorded by the frequency meter, the personal element makes itself visible in the results; straight lines appear wavy, and the synchronism is not at all good. I therefore tried very carefully calibrating the motors by timing first, and then arranged that, once started, the motors should not be touched; the gain in speed of each is approximately the same if both motors are run from secondary batteries of the same ampere-hour capacity, and in this way we have obtained the most perfect results as regards synchronization.

The great advantage of this process is that the whole operation is in full view, whereas with systems in which the received picture is obtained on a photographic film one has to develop such film before it is possible to discover whether anything is wrong. With the receiver described, the operator keeps his hand on the sliding contact of the resistances, and merely adjusts their position during the first two or three seconds, according to the condition of the electrolytic marks, i. e., whether crisp and concise or not. The transmitting cylinder can be used as the receiving cylinder, and the apparatus is thus reduced to the limits of simplicity.

Toward the end of last year I designed a portable machine, two of which Mr. Sanger-Shepherd has just completed, embodying in them a number of improvements of his own, and these machines, which have worked successfully on their trials, are shown on the lecture table to-night. They are suitable for line or wireless work, and will, I believe, prove of great value in naval and military operations.

The Daily Mirror inaugurated the Paris-London photographic service in November, 1907, with Prof. Korn's selenium instruments, which I shall briefly describe, as Korn is now making two new selenium apparatus with the view of transmitting photographs from New York to London. In this system use is made of the fact that the electrical resistance of the metal selenium varies according to the strength of illumination to which it is subjected, a beam of light passed through the light and dark parts of a photograph in succession being used to vary the strength of an electric current sent to the receiving apparatus.

In Korn's selenium transmitter light is concentrated from a Nernst lamp to pass through a revolving glass cylinder, round which a transparent photograph (printed on celluloid) is fixed, the beam traversing the film at its brightest part, where the rays come to a focus (fig. 2). The light which passes through the picture is reflected by a

prism inside the cylinder on to the selenium cell, through which the current passes. Across the circuit is shunted a galvanometer of the Einthoven pattern, containing two fine silver strings free to move laterally in a strong magnetic field. These are represented by AB, the magnet poles being MM. When a bright part of the photograph admits of light falling on the sensitive cell, current passes through AB, and it shifts aside, allowing light from a Nernst lamp N_2 to enter the prism P, whence it is reflected on to the second cell SS. The telephone lines connecting the two instruments go direct to the wires of a similar galvanometer, which is in series with the galvanometer of the transmitting instrument. If we imagine MM to be the receiving galvanometer, then we remove the prism P, and the light acts on a sensitive photographic film attached to the drum C, which revolves synchronously with the glass cylinder of the sending instrument.

The inertia of selenium once overcome, the metal immediately becomes of great use for many purposes. Prof. Korn's method of com-

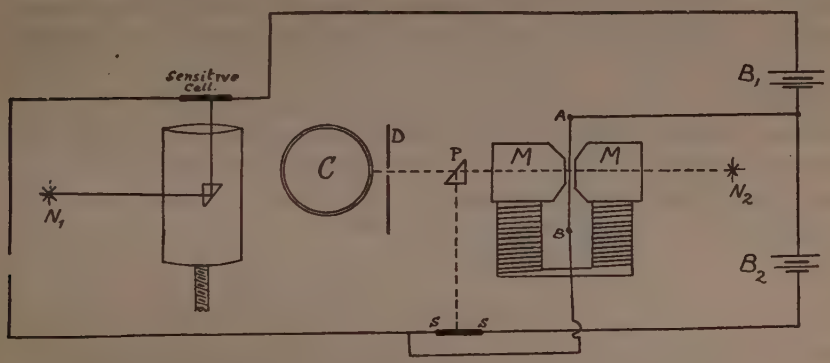


FIG. 2.

pensation is to let the light fall at the same time on two cells of opposite characteristics; one has great inertia and small sensitiveness, the other low inertia and great sensitiveness. By using the two cells on opposite sides of a Wheatstone bridge, dividing the battery into two parts for the other sides, the deflection in the galvanometer is very rapid. You will see the effect from the two curves now shown on the screen. That above the axis along which exposure is measured is the sensitive cell; that below this axis the cell of low sensitiveness. Clearly the current passed through the galvanometer is that obtained by joining the sums of the ordinates. This gives the small curve shown as the shaded portion. When the illumination is thrown on the cell the current rises very rapidly instead of gradually, whilst when it is suddenly shut off (at P in the upper curve) it drops to zero almost instantly instead of falling gradually.

I shall now show, by means of a meter, an image of the pointer of which will be projected on to the screen, how the inertia of selenium

is overcome. You will first see that if I take away the screen so as to allow light to fall on the selenium cell, current passes into the galvanometer, and the needle slowly deflects several degrees. Now, I quickly shut off the light by intercepting it with the screen, and the needle comes slowly backward. Such sluggish movement would be impossible for the purposes of photo-telegraphy, where at least half a dozen changes per second are required to be recorded abruptly even in transmitting the simple portraits to which the selenium process is limited.

Now, using two cells of different characteristics and a Wheatstone bridge arrangement, I will once more allow light to fall suddenly on the two cells simultaneously, and you will see that the galvanometer needle records the change in resistance of the combination quite quickly; the combination is even more noticeable when the light is suddenly shut off again, the needle returning to zero with great rapidity. This compensated arrangement of selenium cells at once renders their use of practical value for various physical and optical measurements. Prof. Korn has found that for an increase in the illumination δI, the current obtained is given by the equation $y = \alpha.\delta I.e^{-\beta t - \frac{1}{m}}$, where y is the current, α the sensitiveness of the cell, β and m its inertia constants, and e the basis of Naperian logarithms. For two cells to be combined to the greatest advantage we must have them such that if their equations are respectively

$$y_1 = \alpha_1 \delta I.e^{-\beta_1 m \quad -\frac{1}{t}}$$

and

$$y_2 = \alpha_2 \delta I.e^{-\beta_2 m \quad -\frac{1}{t}}$$

then

$$\frac{d(y_1 - y_2)}{dt} = 0.$$

This makes the condition for good compensation that

$$\alpha_1 \beta_1 = \alpha_2 \beta_2.$$

m is usually almost constant, and with suitable Giltay cells is about $\frac{2}{3}$.

In practical language, the condition for compensation is that the principal cell should have great sensitiveness and a small inertia constant, the compensation cell low sensitiveness and a high inertia constant, the product of sensitiveness and inertia constant being the same in the case of both cells.

The physical properties of selenium are of such importance that I feel I may be allowed to digress for a few moments to show one

way in which they may be utilized to solve a problem that has long occupied many investigators, viz, the satisfactory measurement of the beam of heterogeneous rays from an X-ray tube. Whenever a new tube is used in radiographic work, a different voltage, or different interrupter or coil, the time of exposure for the photographic plate has to be determined anew. The strength of the tube under any conditions can, however, be determined by means of a simple piece of apparatus which I have constructed, the working of which I shall now be able to show you.

If the X rays fall on a fluorescent screen of barium platino-cyanide, the screen absorbs them and emits yellowish-green visible rays; this transformed energy is capable of affecting a very sensitive selenium

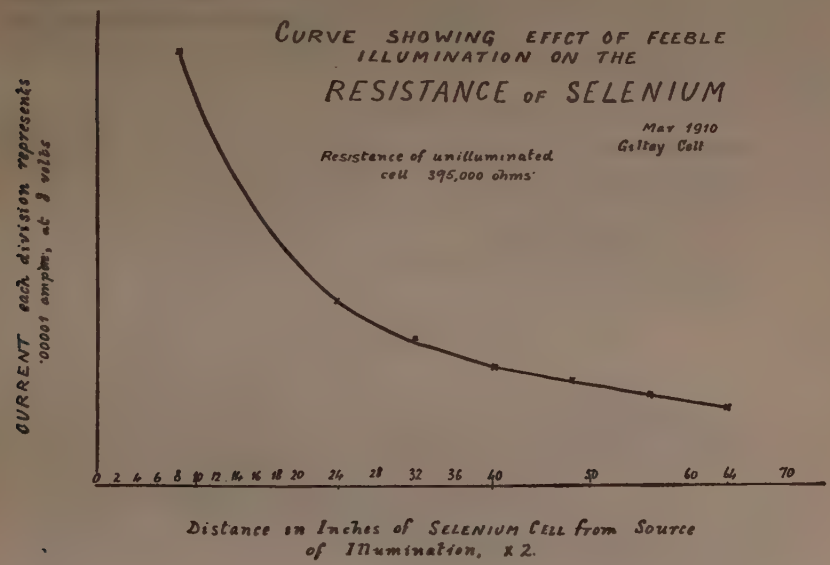


FIG. 3.

cell when placed in contact with the screen, the resistance becoming less the greater the fluorescence. You will see here a selenium cell of approximately 395,000 ohms resistance, over which is placed a small fluorescent screen of the same size; the cell is put in series with a battery of 100 volts and a milliampere meter, the divisions of which may be made to correspond to some arbitrary scale or to the time necessary for the exposure of a given make of photographic plate.

The dividing of the dial depends on two things: First, the characteristic curve of the selenium cell connecting its resistance with the strength of illumination, the linear distance of the source from the cell being, in this case, the most convenient to employ. Second, this characteristic curve must be modified to meet the case of illumination by the rays from the antikathode, which do not necessarily

diminish in their power to make the screen fluoresce as the square of the distance from it. You will see on the screen the characteristic curve of a selected selenium cell for feeble illumination, the maximum being of about the same wave length as that of the fluorescence, showing the relation between resistance and distance separating the source of illumination and the cell, and also the modified curve showing a similar relation between resistance and distance between antikathode and cell, with the screen in contact. The portion of the first curve most nearly asymptotic is best to employ for the work, and from the second curve the dial scale of the meter can be easily calibrated. If, now, I vary the height of the X-ray tube from the measuring apparatus, you will see that the meter needle is deflected less as the distance between tube and cell is increased. The actual instrument is provided with a scale divided so as to show comparative times of exposure, and by its use radiographic work can be greatly facilitated.

It is interesting to note that the effect of the rays on the fluorescent screen, as estimated by the selenium cell, differs less with increasing distance the farther the antikathode is from it:

Distance of antikathode from apparatus.	Current recorded.	Difference.
Inches.	*Milliamperes.*	
6	0.33	—
8	.27	0.06
10	.22	.05
12	.20	.02
14	.18	.02
16	.16	.02

A good deal of time has, I am afraid, been taken up in giving details of apparatus, but I will now show some of the results that have been obtained in practice. The selenium machines already referred to were operated between Paris, Manchester, and London until the end of the year 1908. The first photograph received (slide) was of King Edward, and was received at the Daily Mirror installation in November, 1907. Several results will now be shown in the lantern, and you will observe that they are all composed of parallel lines, which widen or "thin" according to the density of the picture. These lines correspond to the movement of the shutter attached to the strings of the Einthoven galvanometer, which regulates the thickness of the spot of light focused on the revolving sensitive film. This spot of light traces a spiral line around the film, which, when developed, is laid flat, and the spiral becomes resolved into so many parallel lines.

Late in 1908 Prof. Korn introduced his telautograph, in which a Caselli transmitter, such as already described for the telectrograph, is used, and a line sketch or half-tone photograph is attached to the drum. The receiver is similar to that used in the selenium machines, a spot of light cast on a revolving sensitive film being shut off every time current flows through the wire of the galvanometer and displaces it. When displaced the shadow of the wire falls over a fine slit placed in front of the film, and so prevents the light from passing through to it. A line sketch transmitted from Paris to London in this way is now shown (pl. 2, fig. 2). The methods of synchronizing the sending and receiving cylinders is the same as that used in the telectrograph; but Prof. Korn's work was done prior to mine, and his arrangements were therefore copied by me. Similar methods have been adopted for many years, however, in certain systems of ordinary telegraphy.

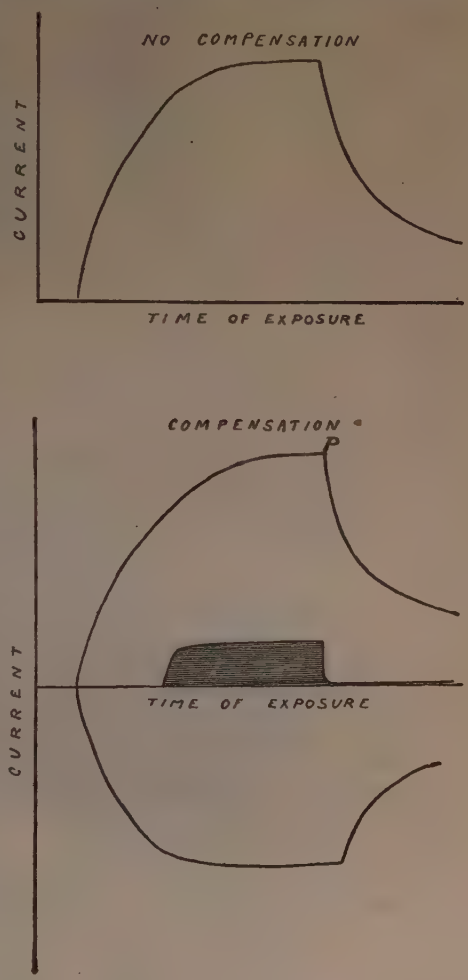


Fig. 4.

There is a great deal of interesting matter connected with the efficiency of the galvanometer-receiving apparatus, and the vast amount of careful work done by Prof. Korn to increase it, which time quite forbids my mentioning, and I will therefore pass on to the latest phase of phototelegraphic work—the experiments now being carried out to effect wireless transmissions.

The wireless apparatus for transmitting sketches, writing, or simple photographic images over distances up to about 50 miles may perhaps be looked upon as rather rudimentary, but I shall be able to show, from actual results, that it is at any rate practicable, and it is certainly more simple than any method based on later wireless researches.

I will first show you an experiment, for the simplicity of which I must ask your pardon; but it illustrates so clearly how easy it really

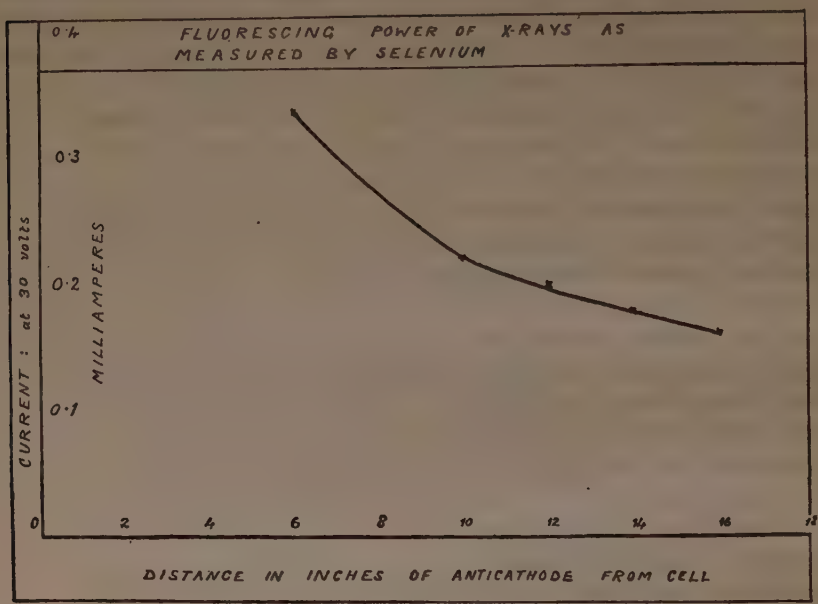


FIG. 5.

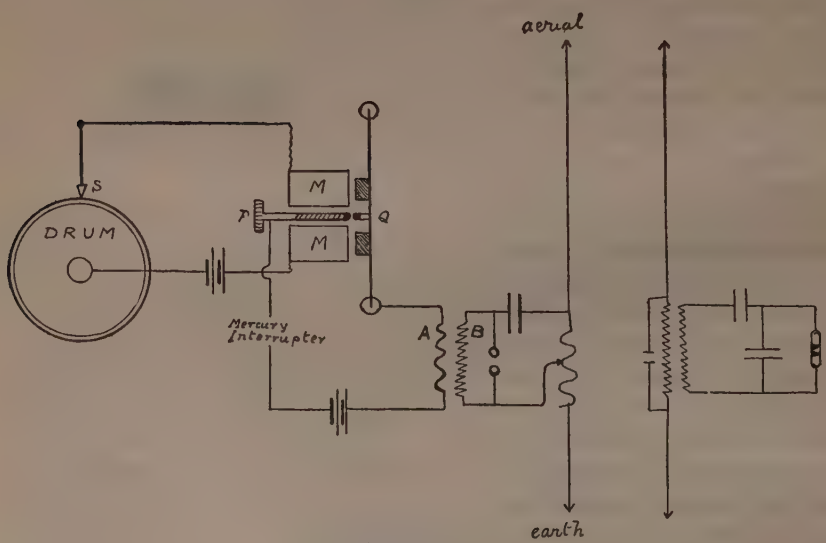


FIG. 6.

is to transmit a photograph by wireless under ideal conditions. I have here a small electric lamp, coupled up with the local side of a relay and battery, the relay being actuated by means of a coherer de-

1. PHOTOGRAPH WIRED FROM PARIS TO LONDON BY THE AUTHOR'S TELECTOGRAPH.

2. FASHION PLATE TRANSMITTED BY PROFESSOR KORN'S TELAUTOGRAPH.

tector. At the other side of the platform there is a Morse key, which, when depressed, closes the primary circuit of an induction coil, the secondary being coupled up in the usual way to give oscillations. When I press the key, and thereby send a signal, you see that the lamp at once lights up. If the coherer be tapped, the lamp is extinguished, and another tap of the Morse key causes it to light again.

Now suppose that the taps of the Morse key were controlled by the lines in a photograph or sketch, and that the light from the lamp were concentrated on a revolving photographic film, and you will see at once how a photograph could be transmitted by wireless telegraphy.

Such a process would be utterly impracticable commercially, but my telectrographic system can be used with success in its place. A line picture prepared in the way already described is attached to the drum of the transmitter, and the intermittent current, which is ordinarily passed into the telephone line, goes into an electromagnet, M in figure 6, which then attracts a soft iron diaphragm attached to brass springs, which are fixed to two rigid supports. Every time current flows through the magnet coils this diaphragm is attracted to it, and the platinum contacts PQ are brought together; when the current flows, and PQ are in contact, the primary circuit of a transformer is closed, and the secondary having a spark gap and being inductively coupled to the aerial and earth, a signal is transmitted into space. Thus in the wireless transmitter the only difference from ordinary telegraphy lies in the fact that the length of the signals and their distance apart are regulated by the lines composing the sketch or photograph.

When working with high voltages in the primary, such as 110, arcing is liable to take place, and hence the distance between P and Q when not attracted must be considerable. This means that the distance between the diaphragm clamps must be short, and the German-silver spring of which the diaphragm is made must be thick, these two conditions making the natural period of vibration very short. I have, however, found that by interposing a mercury motor-interrupter in the primary circuit, arcing is almost entirely avoided, as if an arc be formed the current is interrupted an instant later, and the arcing ceases in consequence.

The receiving apparatus is very simple, and depends, for short-distance work, upon a coherer cymoscope, the decohering apparatus being of a particular character. Every time an oscillation passes to the antenna, the coherer becomes conductive in the ordinary way, and a relay is actuated; this relay is usually made to start a hammer vibrating, the hammer hitting the coherer, and thus causing it to lose its conductive power. But a vibrating hammer is useless for the photo-telegraphic receiver, and it is essential to have one strike only on the coherer for each signal detected.

The form of apparatus I have employed for this purpose is seen diagramatically in the next lantern slide (fig. 7). EE is the magnet which is actuated by the relay R. It then attracts an armature MN, which moves toward the magnet poles and brings a resilient hammer H, fitted with a platinum contact *p*, against the coherer. The coherer AB is also fitted with a collar F and contact pin, so that in the act of striking the coherer the hammer closes a local circuit, and so causes a black mark to appear on the chemical paper. Successive distinct marks can be obtained in 0.017 second in this way, which is considerably more rapid, I believe, than a decoherer was given credit for.

There is not sufficient time to show an actual transmission by wireless, and I should like to make it clear that only sketches of the simplest character are at present being transmitted; but, as you will see from the result thrown on the screen—a simple portrait of His

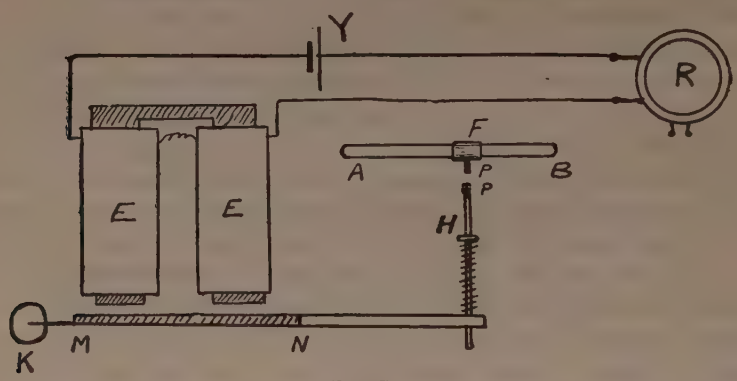


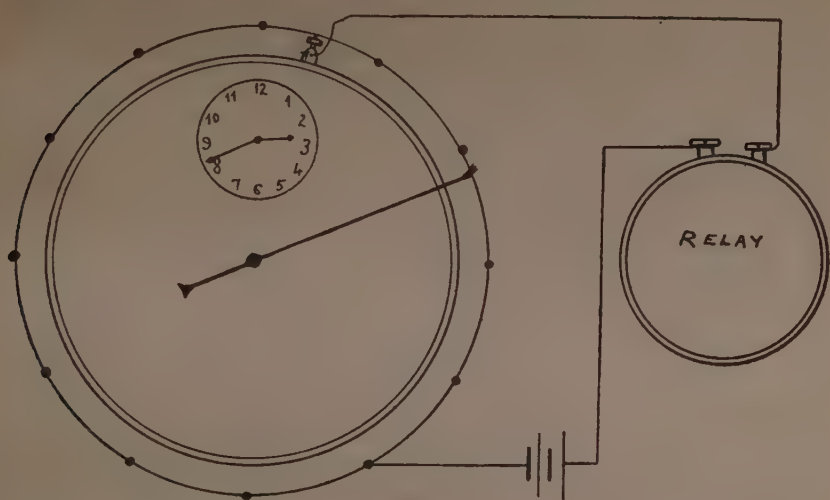
FIG. 7.

Majesty the King—the images are recognizable, and merely require slightly more detail to make them quite comparable with the early results in line obtained by Prof. Korn's telautograph.

Another result shows a plan transmitted by wireless; here an island is seen represented, and a lighthouse—or it might be a fort—and by means of letters the positions of sections of an army on the island are supposed to be designated, while the shaded portion might mean that the "enemy" is in that part of the island. Such plans as these could be drawn direct in shellac ink on a slip of metallic foil, placed upon a portable machine coupled to a portable military wireless set, and communicated from one section of an army to another. The small portable machines I have already shown are used for the wireless transmissions, and they possess the advantage that "tapping" of the communications would be quite impossible. It is for this reason that I think the method would be of such value for military and naval purposes; even supposing that anyone wishing to

intercept a plan or written message were to have an exactly similar instrument, with the same dimensions, screw threads, and so on, by merely altering the rate of running by 5 or 10 per cent, according to prearranged signals, the picture as received by the intercepting party would be quite unintelligible and confused.

We have already seen that in the telegraphy of a picture by any system, accurate synchronizing of the sending and receiving apparatus is essential. Where a metallic circuit links the transmitting and receiving instruments together, the matter is an easy one, and we have seen in what way it is effected. But when dealing with wireless work, the question of synchronism becomes more serious. I have employed two methods, each of which appears to answer



CHRONOMETRIC SYNCHRONISER FOR WIRELESS APPARATUS.

Fig. 8.

satisfactorily, and as they are very important I will devote a few moments to their description.

The first method secures accurate synchronism independently of any wireless communication. You have already seen how, in the ordinary telegraphic work, the receiving cylinder is driven rather faster than the sending one, and when it finishes up a complete turn too soon it is arrested until the sending cylinder has caught it up, when the latter sends a reverse current, which is responsible for its release. But in the wireless apparatus both sending and receiving cylinders are driven too fast, so to speak—that is, they are made to revolve in four and three-fourths seconds instead of a nominal five. A check comes into play at the end of the revolution, and the cylinder is stopped until the five seconds are completed, the motor working

against a friction clutch in the ordinary way during the stop. At the end of the fifth second each cylinder is automatically released by chronometric means, in the manner shown in the next diagram (fig. 8).

Here you will see that a special form of clock is used, with a center seconds' hand which projects beyond the face by about an inch, and to the end of it is attached a brush of exceedingly fine silver wires. At every twelfth part of the circumference of the clock dial is fixed a platinum pin, and consequently every five seconds the little brush wipes against the convex surface of one of them. Each of these pins is connected with one terminal of a battery B, the other side of the battery leading to the relay R, as does also the center seconds' hand. Therefore each time the brush wipes against a pin the circuit is closed, and the relay throws into action the local circuit connected up with the terminals TT. This circuit excites an electromagnet, which attracts an armature and pulls away the check which is holding back the cylinder. At the end of each five seconds the cylinders consequently recommence turning.

Well-calibrated clocks of the pattern used will keep good time for the period taken to transmit a picture, one gaining on the other quite an inappreciable amount, depending on the friction of the brush against the pins. By this means the two cylinders are kept in very fair synchronism independently of any wireless communication, and the less the interval between the stopping and restarting of the cylinders be made, the more accurate and satisfactory will be the effect.

The other method of synchronizing is controlled by electromagnetic oscillations. Let us suppose that a coherer is being used as cymoscope; the transmitting cylinder is kept running without any interruption, but by means of a fleeting contact it sends out a wave at the conclusion of its turn, a bare space in the picture being necessary about half a second beforehand, so that no waves are sent out for the half-second previously. The receiving cylinder is driven too quickly, and checked at the end of the revolution. It then, by means of a cam pressing down a spring lever, throws out of circuit the marking current, and brings into circuit the relay which actuates the electromagnetic release. Consequently, when the synchronizing wave is received, the coherer causes the relay to work, the release is effected, and the receiving cylinder starts a new revolution in unison with the transmitter.

This means of synchronizing is only possible in cases where a cymoscope is employed that is capable of actuating a relay, and you will therefore see that it is out of the question, except for short distances. I am therefore using the chronometric system already described in the apparatus, and it is being embodied in the quartz fiber apparatus I am now about to describe. I must first remark that the

wireless work has been greatly facilitated by the courteous assistance so readily given by the Marconi Company.

The general form of the Einthoven galvanometer is well known, and the modified type of it used by Prof. Korn for phototelegraphic purposes has been already shown. If, now, we make the magnetic field very much more intense by building the field magnets heavier, and using a large number of ampere turns in the winding, and also employ a "string," which is very much more elastic than the silver ribbon, the displacement of the string will be correspondingly greater. The silvered quartz fiber used by Duddell for this purpose gives an extremely sensitive instrument, and very appreciable displacement is obtained with the current from one dry cell passing through 35 to 90 megohms resistance.

It is not long since Prof. Fleming explained at this Institution the valve receiver for detecting wireless oscillations; in ordinary wireless telegraphy, the minute alternating currents are rectified, and sounds are heard in the telephone in circuit owing to small unidirectional currents. If these currents be passed through the silvered quartz string of the galvanometer, the string is shifted. If, therefore, we cause a shadow of the string to lie over a fine slit, any displacement will cause the slit to be opened, as it were; the shadow will be shifted off the slit, and light will be free to pass through it. Oscillations corresponding to the lines in a photograph or sketch could therefore be utilized to cause shifting of the shutter in the manner I have already described for Korn's telautograph, and a sensitive photographic film could be revolved on a drum behind the slit to receive the picture. Such an apparatus is now in course of preparation; but the amount of light that passes through the slit is extremely small, owing to the fineness of the fiber. Mr. Sanger-Shepherd has therefore attached a minute shutter to the fiber, crossing the optic axis; this enables me to use a very much wider slit, and also to adopt the alternative procedure for reception, which you will now see represented in the diagram on the screen.

For photographic reception, the oscillation is passed into the valve detector, and thence to the quartz fiber AB, which is stretched across the field of the magnets (not shown), the poles of which are bored with a tunnel, through which the beam of light is directed. When the fiber is displaced, light is enabled to pass through a fine slit W, and so act on the photographic film. Where, however, the shutter is attached to the fiber, a much wider slit can be used, and then a pair of narrow compensated selenium cells SS are placed behind the slit W, a positive lens being interposed. When a signal corresponding to a dot in the photograph (i. e., the traversal of a line by the stylus) is received, the fiber shifts, light falls on the cells SS, and their resist-

ance is decreased sufficiently to enable the battery E to actuate the relay R. This closes a local circuit, in which the telectrograph receiver is included, and a mark appears on the paper. In this way a visible record is obtained, which greatly facilitates the process.

Wireless phototelegraphy may eventually prove of more utility than the closed-circuit methods, because it would bring America within reach of this country, and would enable communication to be made where telephone or telegraph lines did not exist. It is not limited to photographs—banking signatures, sketches, maps, plans, and writing could be transmitted. But I would point out most particularly that the work is as yet in the very earliest stages, and that in giving you some account of it to-night I may be bringing before your notice methods and systems on which a few years hence you will look back with a smile—as curious merely from a historical point of view.

MODERN IDEAS ON THE CONSTITUTION OF MATTER.[1]

By Jean Becquerel,
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For a number of years past physicists have been laying the foundations of a new theory of matter. A series of bold conceptions, based on unlooked-for facts, has worked a deep-seated transformation in the previously accepted ideas concerning the constitution of bodies.

Everyone knows that substances in general are divided into two groups, simple bodies or elements and complex bodies made up by the combination of these elements. For a long time these bodies have been considered as composed of atoms which have combined and formed molecules, the atom being the most minute quantity of matter characteristic of an element and capable of entering into chemical combinations, while the molecule of a body, simple or complex, is the smallest particle of this body which is capable of existing in a physical state. Let us consider an example: The molecule of water, the smallest quantity of water which can exist in a physical state, is the result of the combination of two atoms of hydrogen with one of oxygen. I shall repeat before you the classic experiment of decomposing water by an electric current; oxygen is set free at the positive pole and hydrogen at the negative pole, the two gases coming off in the proportion of two volumes of hydrogen to one volume of oxygen.

The molecule of a complex body is always made up of the atoms of at least two elements. The molecule of an element may be made up of only a single atom, as is the case with monatomic bodies such as helium, zinc, cadmium, or mercury, while in other cases the molecule of a simple body may be a group of several atoms of this body, for instance, hydrogen and oxygen are diatomic, while phosphorus and arsenic are tetratomic.

The discovery of Gay Lussac concerning the laws of the composition of gases led Avogadro and Ampere to declare that gases con-

[1] Lecture delivered at the Museum, Apr. 10, 1910. Translated by permission from the Revue Scientifique, Paris, 48, No. 14, Oct. 1, 1910.

tained in equal volumes the same number of molecules, and that the definite proportions in which they combined represented the invariable relation between the weights of the atoms which were in juxtaposition.

The theory is that in the interior of bodies the constituent molecules are perpetually animated by a movement which becomes correspondingly greater as the temperature becomes higher. If the swiftness of these thermic movements could be gradually reduced to zero, temperatures would be obtained which would approach more and more closely to the limit of temperature found at about —273° C. This temperature, the lowest conceivable, since it corresponds to a state of repose of the molecules, is called absolute zero.

The principles of mechanics which apply to this conception of molecules in movement takes account of all these laws to which gases and dissolved bodies are subjected. I can not enlarge here on the methods which have made it possible to count in a cubic centimeter of gas at ordinary temperature and pressure, thirty billion billions of molecules, and to evaluate the dimensions of one of these molecules. The diameter of a molecule of oxygen, for example, is a few ten-millionths of a millimeter. These figures give some idea, however, of the extreme divisibility of matter. In connection with this divisibility of matter it is interesting to recall that according to Berthelot the odor of one hundred-thousand-millionth of a gram of iodoform per cubic centimeter of air is perceptible to the sense of smell.

You are all aware that matter attracts matter, in accordance with the universal law of gravitation which rules the movements even of the stars. The invariability of the constant of gravitation has suggested the idea that the atoms of all bodies can be formed by the unequal condensation of a single principle and the relations discovered by chemists between the different elements lend themselves favorably to this hypothesis.

The idea of a single principle as the ultimate constituent of all things, dates in reality from the most ancient times. Twenty-five centuries ago, Thales propounded the existence of a primordial fluid to which he attributed a sort of soul and a power of attraction. Anaximander, Anaximines, and Herodotus spoke of a universal principle, and Pythagoras located above the air "ether, a celestial substance free from all perceptible matter." Five hundred years before our era Leucippus and Democritus had conceived of atoms indivisible and eternal which moved about in infinite space; Lucretius a little later expounded similar doctrines. Finally Descartes and Leibnitz developed for themselves an idea of matter which led them to similar conclusions.

About the end of the last century an English chemist, Prout, propounded the hypothesis that all elements could be made up by the progressive condensation of hydrogen, the lightest of all the bodies.

Several years ago, however, modern physicists took a still further step; they now attribute an atomic structure not only to matter, but to electricity as well, and consider matter as composed of electricity.

We shall see as a fact that electrified corpuscles have been isolated which themselves appear to be composed of electricity, entirely free from anything that can properly be termed matter, whose mass is of electro-magnetic origin and is nearly two thousand times as small as that of an atom of hydrogen.

These atoms of electricity are called electrons. They are present in all bodies; they are the atoms which are at the source of all phenomena of light, and again they are those atoms which allow the conduction of heat and of electricity. The electron appears to be in the nature of a universal constituent of matter, without being itself matter, in the ordinary sense of the word.

The first conception of an atom of electricity is a result of the phenomenon of electrolysis, of which you may see an example in the decomposition of acidified water by an electric battery. A solution which is a conductor of electricity and is decomposible by a current is termed an electrolyte. Every molecule of an electrolyte is separable into two atoms or atomic groups, called ions, which possess charges of equal quantity and opposite signs; thus, when sodium chloride is dissolved in water a certain number of molecules dissociate into negative chlorine ions and positive sodium ions. Under the influence of the molecular movements which go to make up heat and consequently from the shocks resulting therefrom there is a constant recombination of the ions and fresh decomposition of the molecules. In a very dilute aqueous solution, however, nearly all the sodium chloride is found to be in a state of dissociation. Now, if two electrodes connected to the poles of a battery are dipped into the solution, the negative ions (chlorine) are carried to the positive pole (anode) and the positive ions (sodium) to the negative pole (cathode).

The laws of electrolysis, established by Faraday and worked out completely by Edmond Becquerel have led to the conclusion that all the *univalent* ions, such as hydrogen, chlorine, sodium, and potassium, always carry the same charge (negative or positive), while the bivalent ions (copper and the like) carry a charge just double the preceding, and so on. The charge of the univalent ion is the smallest charge that has ever been observed, and when separated from its material support constitutes the electron or atom of electricity.

This elementary charge has been susceptible of measurement. It is easy to evaluate the quantity of electricity necessary to liberate a gram of matter—for example, a gram of hydrogen in the electrolysis of water—and thus to obtain the total charge of the hydrogen ions. These ions correspond to the molecules, and as the number of molecules in a gram of hydrogen is known, the charge carried by a single ion may be determined. This charge is very minute; it amounts to 4.10^{-10} in terms of the C. G. S. electrostatic unit.

The study of the radiations obtained in rarified gases has also been of assistance in making our knowledge of the atom of electricity more definite. When an electric discharge is produced in a gas by means of a static machine or an induction coil under ordinary pressure a disruptive spark is obtained. In a tube where the pressure is reduced the aspect of this spark is changed and when the pressure is not more than a few millionths of an atmosphere (Crookes's vacuum) a ray emanating from the cathode (negative pole) may be observed. Whatever may be the position of the anode or positive pole, this cathode ray is emitted perpendicularly to the surface of the cathode and is sent out in a straight line. The glass of the tube where the radiation strikes it takes on a beautiful green fluorescence. These cathode waves excite phosphorescent bodies[1] and heat screens placed in their path.

These rays emanating from the cathode bear the name of cathode rays. They were discovered in 1869 by Hittorf, and have since been made the subject of study by a great many physicists, among whom are Crookes, J. J. Thomson, Jean Perrin, Marjorana, Lenard, Wien, Villard, and others. Sir William Crookes was the first to propound the hypothesis that they were due to a fourth state of matter, the radiant state, which took shape as a molecular bombardment, as it might be called. This truly remarkable idea met with much incredulity, as at that period (1880) the tendency of most men of science was to attribute all such phenomena to a vibratory movement and not to a flow of matter itself. Many physicists, therefore, considered the cathode rays to be due to undulatory movements analagous to light. This interpretation was soon to be abandoned, however. Later experiments confirmed in the most startling manner the ideas of Sir William Crookes, subject only to the qualification that the radiant state was due in the cathode rays not to a bombardment of particles of matter, but to a bombardment of electrified corpuscles which were much smaller than the molecules of known bodies and which were no other, as we shall see later, than negative electrons free from matter.

[1] Experiment: A bouquet of phosphorescent material rendered luminous by cathode rays.

In December, 1895, M. Jean Perrin succeeded in a fundamental experiment. He demonstrated that the cathode rays carried negative electricity, and he charged with negative electricity an insulated cylinder placed in a grounded metallic vessel.[1]

Let us consider now some other properties of cathode rays. If they traverse an electric field—that is to say, if they are passed between two electrified metallic plates, one positive and one negative, a pencil of these rays describes a parabola, as would be expected of a stream of corpuscles attracted by the positive plate and repelled by the negative plate.

If submitted to the influence of a magnet (magnetic field) the pencil is curved and describes a helix around the lines of force.

These two deviations, electric and magnetic, allow, as Sir J. J. Thomson has shown, the measurement of the velocity of propagation of the corpuscles, as well as the relation between the electric charge carried by a corpuscle and the mass of the corpuscle. Other methods have also led to the estimation of the same quantities with the following result: The velocity of the cathode corpuscles varies, according to the conditions of the experiment, between 30,000 and 100,000 kilometers per second. The ratio of the mass to the charge is 2,000 times as small as that of the hydrogen ion in electrolysis. This ratio is always the same whatever the electrodes or the rarified gas in the tube happen to be. Here is a first important experimental result.

At the same time that these researches were being carried on, experiments were being made on radioactive bodies, whose study has led to conclusions of at least equal importance.

You all know that certain bodies possess the property, discovered in February, 1896, by Henri Becquerel, of spontaneously giving out radiations of various sorts without any energy being furnished to them.

The electrified particles emanating from these bodies ionize the air—that is to say, by tearing electrified corpuscles away from the molecules of gas and surrounding these corpuscles with neutral molecules, they cause the formation of electrical nuclei which render the air electrically conductive.[2] It is on account of this fact that these rays discharge electrified bodies.

Of the three varieties of rays which emanate from radioactive bodies, one group, the β rays, are charged with negative electricity and are formed of corpuscles identical with the cathode corpuscles, which may be determined by measuring their deviation in an electric field and in a magnetic field. Henri Becquerel has shown that

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[1] Experiment: Deviation by a magnet of a sheaf of cathode rays determined by an opening made in a screen placed a few centimeters in front of the cathode.

[2] Experiments: (1) Discharge of an electroscope by the radiations emanating from a radium salt. (2) Increase of the discharge distance of a spark in the vicinity of radium.

as long as their velocity does not approach too closely the velocity of light, the value of the ratio of the charge to the mass of each corpuscle is just the same as that of the cathode rays.

Again, these same corpuscles are given out by incandescent metals, and liberated by the action of ultra-violet light or of the X rays on metals. In all these manifestations of the phenomenon the same ratio of charge to mass is found.

I can not describe here the remarkable methods due to the work of Messrs. J. J. Thomson, Townsend, and H. A. Wilson, which have made it possible to measure the charge of a cathode corpuscle; I will only indicate the principle on which they are based. When ions are formed in the air—we now call all electrified centers ions—they condense water vapor out of a supersaturated atmosphere and each electrified particle forms the nucleus of a particle of condensed water.[1] The velocity of the fall of these particles allows the calculation of their size, and by evaluating the total quantity of condensed water the number of particles can thus be determined and therefore the number of ions. Furthermore the quantity of electricity carried down by the mist formed can be measured and from that the charge of each ion can be calculated, since their number is known.

The result is a fundamental one; cathode corpuscles and gaseous ions carry the same charge as an atom of hydrogen in electrolysis, and yet their mass is two thousand times as small as that of an atom of hydrogen.

As a necessary conclusion, therefore, it follows that *the cathode corpuscles, the β rays, carry an atom of negative electricity and possess a mass two thousand times as small as the lightest of known material atoms.*

We have just seen how our knowledge of negative electrons is a result of the study of electric phenomena and of radioactivity. In an entirely different branch of physics, however, in the field of optics, the theory of electrons has found an extremely remarkable confirmation.

The theory of Fresnel and the results derived from the experiments of Foucault and Young have established the fact that light is a vibratory movement, and that consequently there exists a medium of such a nature as to transmit the luminous waves. This medium has been called *ether*. It is known by the properties of the movements which are capable of being produced and propagated in it; it exists everywhere—in the interior of matter as well as in spaces free from matter, such as a vacuum.

[1] Experiment: A spark is discharged in the inside of a tube to produce ions; as soon as the air is cooled by expansion so that it is supersaturated, a heavy mist forms about the ions.

Maxwell and Hertz have demonstrated that the phenomena of light are nothing more than a particular manifestation of the electromagnetic phenomena such as induction, hertzian waves, etc., which may be produced in the ether.

Everyone is familiar with the decomposition of white light by a prism resulting in the formation of a spectrum in which the colors spread out as in a rainbow. When the light produced by an incandescent gas is analyzed with the aid of a spectroscope, the observer sees a number of separate brilliant lines. These *emission* lines are as a matter of fact images of the slit through which the light passes before falling on the prism which separates the radiations of different colors. These brilliant lines can be transformed into dark *absorption* lines when a vapor is traversed by a continuous ray of white light; the black lines then indicate the arrested colors. Different bodies in a solid state or in solution likewise show characteristic absorption spectra.[1]

The existence of these emission and absorption spectra, and more generally the fact of all the changes undergone by light waves in a body whether at rest or in movement, shows the intervention of matter in the phenomena of which ether is the seat. In order to explain the reciprocal effect of ether and ponderable matter Lorentz conceived the idea that light phenomena had their origin in the movements of electric charges inclosed in the atom. A remarkable discovery made in 1896 by Zeeman added to the strength of Lorentz's views.

Zeeman discovered that under the action of an intense magnetic field the spectrum lines of a gas are decomposed into several components, and that these component lines indicate that the movement of the corpuscles is polarized—that is to say, oriented, by a magnet.

Thus, just as in the case of cathode corpuscles, the corpuscles which produce or absorb light may have their movements modified by a magnet. It is consequently certain that they are electrified.

In the simplest case, where the lines of force of the magnet are parallel to the luminous line, each line is decomposed into a double ray whose components correspond to two vibratory *circular* movements of the corpuscles in opposite directions.[2]

According to the theory of Lorentz the amount of separation of the components allows the calculation of the ratio of the charge to the mass of the corpuscles, and the direction in which a magnetic field of determined direction displaces the components corresponding to the circular vibrations, indicates the sign of the electric charge effecting the movement.

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[1] Experiment: Emission spectrum of an electric arc and absorption spectrum of nitrate of didymium.

[2] Projection of a slide representing Zeeman's effect on several of the iron lines (spark spectrum).

The application of this theory to experimental results has shown that *emission and absorption in the spectra of gases and vapors are caused by corpuscles identical with the cathode corpuscles; in other words, by negative electrons.*

Since the discovery of Zeeman numerous experimental and theoretical researches have been carried out with regard to this phenomenon which have thrown a new light on the mechanism of emission and absorption. The action of magnetism on the absorption of light has been observed in our laboratory with solid bodies, crystals, and minerals, and experiments have been made at temperatures as low as the solidification of hydrogen (—259°). We shall touch further on upon the novel and unexpected results which attended these researches.

From the foregoing observation, therefore, we find the electron at the very source of all phenomena of light. According to modern theories the transmission of heat and electricity in metals and also the sound and color of metals are explained by the movements of electrons circulating freely among the molecules. These numerous facts, of which I have given you a résumé, establish the idea that the negative electron which appears in a way tangibly in the β rays is a universal constituent of matter.

We must now take up a vital question: What is the nature of the electrified corpuscle? Is it composed of matter or is it made up of some other essence? Present-day physics seems to have partially solved this problem.

Let us consider an electrified body: In the first place such a body possesses a material mass, in the mechanical sense of the word mass; that is, the ratio of the force acting on the body to the acceleration which it gives that body; secondly, by reason of the fact that the body is electrified, it possesses another mass of electromagnetic origin; as a matter of fact, if it is in movement, it constitutes an element of the current which is flowing.

Now, then, every modification in the intensity and direction of the current—that is to say, in the value or direction of the velocity—brings energy into play and gives rise to an effect of induction in the ether. This induction, which opposes every change in direction or intensity (Lenz's law), is a true inertia of electric origin. It is therefore evident that the electrified body has two masses, its material mass and the electromagnetic mass of the charge which it carries.

Now, it has been demonstrated that electromagnetic inertia should depend on velocity; that it should remain practically constant if the velocity does not reach a considerable figure (less than 100,000 kilometers per second), but that it should increase and approach infinity

when the velocity approaches the velocity of light (300,000 kilometers per second).

We have seen that it is possible to measure the velocity as well as the ratio of charge to mass in the β particles of radium. These β rays form a sheaf of corpuscles which have very different velocities and certain of them attain velocities closely approaching that of light. We understand also that the greater the velocity the smaller the ratio of the charge to the mass; that is to say, inasmuch as the charge can not vary, the greater the mass becomes. This, to be sure, is just what we should expect, and the law of variation of the total mass in terms of the velocity should indicate the relative parts of the two masses in the total mass.

The result is surprising; the variation of the total mass is the same as if the electromagnetic mass existed alone, consequently the *material mass appears to be zero.* In other words, the electron is made up of electricity free from any material support, and is a modification, still unidentified in other ways—perhaps of a whirling nature—of the medium which we call the ether.

Thus we find that the electron is a particular condition of the ether; it has a little the nature of matter in that it possesses mass, which is one of the fundamental properties of matter, nevertheless it is not material in the sense which has heretofore been attributed to the word, since its inertia is merely the inertia of the ether. To sum up, we may picture the electron as an intermediate state between the ether and ponderable matter.

The mass of the negative electron at low speeds is 0.5×10^{-27} gram.[1] Assuming it to be spherical its radius can be calculated, its mass and charge being known. This is found to be 10^{-13} centimeter.

Up to the last few years physicists were always driven to seek a mechanical explanation of physical phenomena. It is due to this, for instance, that Fresnel originated a mechanical theory of light. Such an attempt was very natural, since mechanical phenomena fall under our observation every day and are much more familiar to us than electrical phenomena.

Nevertheless, although according to the theory of Maxwell a mechanical explanation, or speaking more exactly an infinite number of mechanical explanations of electromagnetic phenomena, are possible, still no satisfactory interpretation has been obtained in this manner, and the ether has appeared to be very different from the bodies of which we have knowledge.

In view of the data which have now been acquired, however, men of science have decided not only to search no longer for a mechanical explanation of electromagnetism, but to formulate an electrical

[1] $\frac{5}{10000000000000000000000000000}$ gram.

theory of the formation of matter and of mechanical phenomena. It is evident that all the facts which we have just reviewed lead logically to this point of view.

We find that a corpuscle which appears to be nothing but electricity has been isolated from matter, and that the mass of this electron is entirely of electromagnetic origin. We are therefore forced to take electricity as a point of departure in building up a theory of physical phenomena, and even of matter itself.

If matter is made up of an assemblage of electrons, its inertia is entirely of electromagnetic origin; and it is the ether which surrounds each of these electrons and not the matter itself which is the seat of all energy. I do not wish to go as far as to say that there is no such thing as matter; this merely signifies that it is not well to depend entirely on appearances, and that it is necessary to view matter in a different light from which it has been viewed up to the last few years.

If the inertia of matter is electromagnetic, the mass of bodies depends on their velocity, yet this result from an absolute point of view is contrary to one of the principles on which mechanics are based. It would be well to notice, however, that the problems treated in mechanics are all identified with a particular phase, where the velocity is small in comparison with that of light. This is the case not only in all velocities realized on the earth, but also in all velocities in which the stars are concerned. Under such conditions the mass can be considered as practically constant, and nothing in the mechanics of the past need be affected.

Persons who are not sufficiently familiar with the ideas which have just been reviewed often object that electricity still remains a mystery and the new theories rest on an unknown basis. That is very true; we are ignorant of the primary cause of electricity and we comprehend but slightly certain properties of the ether. But in the mechanical theories of the past, is not the word matter wrapped in mystery just as profound? Is the meaning of the word mass any clearer when we speak of a material mass? Is not the origin of matter when considered as independent of the ether still more obscure than that of electricity which appears to us to be a modification of ether itself?

In any case the electrical theory of matter presents the advantage of simplicity, for it tends toward the unification of all the phenomena which are bound up in the manifestations of a single medium, the ether. The electron, which is at the same time ether and matter, serves as a transition means between the ether of space and the matter which is apparent to us.

The object of electrical theories of matter should be to investigate how the atoms of elements can be made up of an assemblage of

electrons. But present day physics, in spite of the good results which have been attained, is still far from affording a representation of an atom of matter.

We have just seen that physics has attained a rather complete knowledge of one constituent of matter, namely, the negative electron, and that the new ideas are based on the properties of this corpuscle. Now does there exist a positive electron, beside this negative electron? It is evidently necessary that positive charges be present somewhere in matter, but have they an atomic structure like the negative charges, or are they of an entirely different nature?

In the discharges through media of rarefied gases and in the emission of radioactive bodies, besides the negative rays, rays carrying positive charges are found, but these positive rays seem to be in general entirely different from the former.

When holes are pierced in the cathode of a Crookes tube, one may observe behind the cathode sheafs of rays which have passed through each one of the orifices formed, and which are propagated in a direction inverse to the cathode rays. These are the canalstrahlen discovered by M. Goldstein. These rays are positively charged, and, rather remarkably, whatever the gas in the tube may be, the measurement of the ratio of the charge to the mass reveals only two sorts of corpuscles (J. J. Thomson) some corresponding to the atom of hydrogen carrying an elementary charge, and others corresponding to the atom of helium and carrying a double charge.

It is these last corpuscles which, in the emission of radium and all radioactive bodies, form the α rays. Rutherford has demonstrated by some magnificant experiments that these α rays are made up of atoms of helium.

Lastly, there are other positive rays (anode rays) emitted by substances placed at the positive pole of a Crookes tube, which are no other than material atoms which have lost their negative electrons (Gehrke and Reichenheim).

It may be seen, therefore, that the positive rays are quite different from the negative rays; they form a stream of electrified matter and are made up, not of electrons, but of ions, material atoms deprived of one or more negative electrons. These atoms are of a mass at least equal to that of a positive ion of hydrogen, that is to say, an atom of hydrogen charged positively in consequence of the loss of a negative electron. In a word, the positive particles are the *remains of atoms.*

Because these positive charges remain in such a way affixed to particles of matter, many men of science have not admitted the existence of a positive electron similar to the negative electron. Some have even thought that there is no positive electron and that matter itself has an existence independent of electrons, that the union

of matter and negative electrons would give atoms electrically neutral, and that the positive charges would result only from the absence of negative electrons; this view of the case, however, a view which is intermediate between the old and the new ideas, loses all the advantages of simplicity and unification resulting from the modern conceptions, which attributes everything to the ether.

A vital factor in these considerations must be noted in the emanation of helium in the form of X rays from all radioactive bodies, and it must not be forgotten that Sir J. J. Thomson has found these same X rays in the canalstrahlen tubes. The helium ion can not, however, be the positive electron because there exists a material atom, that of hydrogen, which possesses a smaller mass; still the atom of helium presents a grouping of very great stability. Whether it is formed in the preceding phenomena by the direct combination of negative electrons with positive electrons freed at just that instant, or whether it appears as a primordial grouping in the constitution of the atoms of most of the elements are questions which can not at present be answered.

In the canalstrahlen particles characteristic of the hydrogen ion are also found. We can go back to the ideas of Prout and suppose that this ion is nothing else than the positive electron. It would be necessary to know, then, whether its mass is purely electromagnetic. If this is so, the positive electron would have a mass 2,000 times that of the negative electron, and the atom of hydrogen would be the result of the union of a single positive electron with a single negative electron.

Still another hypothesis has been proposed; some physicists who have found great difficulty in explaining the properties of metals by means of negative electrons alone have imagined the existence of two sorts of electrons differing only in the sign of their charges.

I should like to say a few words here about some quite recent experiments made in our laboratory, for which there has been found no simple explanation in the idea of negative electrons, but which could be interpreted in a simpler way if there were positive electrons in the make-up of bodies. These experiments had to do with the action of a magnetic field on the absorption bands of crystals and of certain dissolved salts. The change of period produced by the magnetic field took place in certain bands in the direction which would correspond to negative electrons, but manifested itself in the opposite direction with other bands.

The size of the change of period which is absolutely independent of changes of temperature (as far as —259°) appears to be characteristic of a vibrant system. All these phenomena seem to indicate that certain of these systems may contain positive electrons.[1]

[1] Projection of a slide showing this phenomenon in a group of bands of Xenotine at —259°.

Other experiments on discharges in very rarefied gases made first by M. Lilienfeld and then in another form in our laboratory have resulted in obtaining positive rays which may be interpreted by supposing the existence of free positive electrons, but other interpretations have been opposed to this hypothesis, and further researches in this direction must be made.

It is therefore possible that there exists a positive electron of the same nature as the negative electron. I say "of the same nature" and not "identical," because the dissimilarity between the phenomena presented by the two electricities renders it probable that there is a difference between the two electrons. If the two sorts of electrons do exist, according to our experiments they should have the same ratio of charge to mass, but their masses as well as their charges may be very different.

One fact is certain in any case, and this is that the positive electrons if they exist, are very tightly bound to the atoms of matter. They only reveal themselves in magneto-optic phenomena, where the physicist carries his investigations to the very foundation of the atom without breaking it up, or in the interior of tubes of rarefied gases under very special conditions where positive ions are broken up by the shock of the cathode particles acting in the capacity of projectiles.

We can see from this how much the ideas on the nature of positive charges have been modified. Yet whatever the positive electron may be, its nature must be known as well as the negative electron before it is conceivable to understand the structure of an atom of matter.

Nevertheless there are two very interesting systems of explanation which have been developed. Some physicists have conceived the idea that at the center of the atom is a positive charge around which the negative atoms gravitate like planets around the sun. But this hypothesis meets with grave difficulties which I can not set forth here. I think that one should not allow himself to be led astray by the seductive idea of a similarity between the world of the infinitely small and the world of the infinitely great and it seems to me that a group of atoms is in no way comparable to the world of matter.

The system most generally adopted to-day is as follows:

It is imagined that there is a positive charge uniformly distributed over a sphere in the interior of which are situated the negative electrons. The positive charge is equal to the sum of the charges of the negative electrons. The positive electricity tends to draw the corpuscles to the center of the sphere but the mutual repulsion of the negative electrons drives them away from this point and they take up a position of equilibrium and group themselves regularly about the center.

By a simple experiment due to Prof. Mayer, we can reproduce a similar grouping. If we take a number of small steel needles iden-

tical with each other and equally magnetized and stick these needles into corks which float on the surface of a tub of water, they will repel each other mutually in the same way as the negative electrons would do and in accordance with the same law. The force to group them is derived from the pole of a large magnet placed above the tub, the needles are attracted toward a point situated vertically below the pole and for each one the horizontal component of the force of attraction is evidently proportional to its distance from this point.

The conditions imagined for the electrons are thus realized by the needles, the only difference being that the grouping takes place not in three dimensions, but in a plane.

Let us brilliantly illuminate the tops of the corks and project their images on a screen. You can see in this way the representation of this equilibrium. You can imagine that the brilliant spots on the screen represent mobile electrons in the interior of a great positive sphere. It can be seen that these electrons are regularly arranged around a center forming, according to their number, one or more concentric rings.

Sir J. J. Thomson has worked out, with the aid of calculus, the positions of equilibrium which the electrons may assume in greater or less numbers, and has succeeded in explaining in this way the periodic classification of elements discovered by Mendelejeff. It should be noted, moreover, that this way of looking at the constitution of the atom takes account of the phenomena of light. It is impossible, however, to form any idea of the constitution of the sphere over which the positive electricity is supposed to be distributed.

Other conceptions can be imagined, and the field for hypothesis will be unlimited as long as positive electricity remains as mysterious as it is now. It can even be said that the adoption of this or that system of explanation is hardly more than a matter of preference.

In any case, however, it is certain that the atom is of considerable dimensions in comparison with the negative electron. The volume of an atom is sufficient to contain billions on billions of electrons, but as its mass indicates that it contains at most a few thousands, it is certain that the electrons are at enormous distances from each other in comparison with their dimensions. We might liken them to a swarm of gnats gravitating about in the dome of a cathedral.

In spite of our ignorance of the nature of positive electricity, however, the facts acquired in the last 20 years render extremely probable the hypothesis that the constitution of matter is purely electrical. But, then, as all substances are made up of electric charges, the atom of matter can no longer be considered as immutable, and one may say without being an alchemist that the transmutation of matter is not a Utopian idea.

Such ideas as these, whose boldness needs no remark, have already been confirmed in a remarkable manner. Radium gives birth to a gas called the emanation of radium. Messrs. Ramsay and Soddy have shown that this emanation produces helium. Rutherford has proved that the α rays of radioactive bodies are nothing more nor less than atoms of helium. Moureau has recognized the presence of helium in radioactive gases from thermal sources.

We know to-day that radioactive substances undergo an evolution in which there appears a whole series of more or less ephemeral bodies whose duration of existence may be as small as a few days, or even a few seconds, as in the case of the emanation of actinium. All these bodies are new *elements*.

These transformations are veritable *transmutations. They are not chemical decompositions.* They appear to be independent of temperature; they bring into play a considerable amount of energy; for instance, the emanation of radium is, as a matter of fact, capable of setting free 2,500,000 times as much energy as the explosion of a mixture of hydrogen and oxygen of equal volume.

Radium and polonium form part of the series of elements deriving their origin from uranium, and it is very probable that in addition to helium the relatively stable residue of these transformations is nothing other than lead.

Sir William Ramsay at present is carrying out some remarkable experiments. He has announced the transmutation of copper into potassium, sodium, and helium under the action of the concentrated energy which the radium emanation brings to bear on them. In some recent experiments, which appear to be beyond criticism, he has attained the transmutation into carbon of silicon, titanium, zirconium, lead, and thorium. All these bodies belong in the same column in Mendelejeff's table.

These results show the possibility of a transformation of heavy atoms into more simple atoms; that is to say, the possibility of a degradation of elements. It is impossible to imagine for an instant, however, the possibility of realizing the inverse transformation, for example, of copper into gold. Such a transmutation would unquestionably require a colossal amount of energy, and we have as yet no means of disposing of the intra-atomic energy, of which our only knowledge is that it is considerable.

It is probable that all matter is undergoing a process of evolution. The slowness of the transformation, however, or the rarity of conditions favorable to quick change gives us an illusion of stability.

A while ago I recalled several very ancient theories; we know of nothing to-day that contradicts them. Four principal ideas may be derived from these theories, the conception of the atom, the existence

of internal movement, the relation between these movements and the properties of the magnet, and the possibility of transmutation. These ideas we are always calling to our aid in practical work. I may quote here a few lines of Lucretius which are truly prophetic:

"Versibus ostendi corpuscula materiai
Ex infinito summam rerum usque tenere
Undique protelo plagarum continuato."

(The corpuscles, the elements, of matter shall preserve for all eternity and everywhere the uniformity of things by a series of ever-continued blows.)

"Fit quoque ut huc veniant in coelum extrinsecus illa
Corpora quae facient nubes nimbosques volantes."

(It may happen that hither from the worlds beyond may come those bodies which form the mists and the flying clouds.)

According to Lucretius these corpuscles are innumerable and traverse rapidly inexpressible distances, so that you may recognize in these citations the principal properties which we attribute to-day to electrified corpuscles.

However, if certain of these ideas which have just been expounded have inspired philosophers and savants of all ages from antiquity to the present day, still, the idea that electricity can give birth to matter is entirely modern and is due to the discoveries of radioactivity (February, 1896), of the Zeeman phenomenon (August, 1896), and of the nature of cathode rays (1895–1897).

Between the assertions of the ancient philosophers and those of our day there exists a profound difference. The former were never subjected to any experimental confirmation; they were merely conceptions of the imagination and their value is limited by the errors which they included. The latter, however, can be justified by experiments which brook no contradiction and by reason of this confirmation carry conviction with them.

SOME MODERN DEVELOPMENTS IN METHODS OF TESTING EXPLOSIVES.[1]

[With 12 plates.]

By Charles E. Munroe,

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As has previously been pointed out in these pages, the greater proportion and the larger variety of the explosives that are annually produced are consumed in the industries, and a very considerable proportion of these are consumed in the winning of coal. As is well known, this most important industry is attended by many hazards, not the least of which is the constant danger of explosions owing to the presence of fire damp and inflammable dust in these mines. Most serious accidents from these causes, which have been attended with frightful casualties, have frequently occurred, and their frequency and magnitude have increased as the demand for coal has increased until the public conscience has been aroused and efforts have been made by individuals and by governments to devise means by which to reduce the number of these explosions and limit their scope.

Consideration of the conditions attending such of these catastrophies as were carefully investigated made it evident that many of these mine explosions have been initiated by the explosives used in the mines, and therefore the behavior of a large variety of explosive compositions, when fired in dusty and fiery atmospheres, have been studied experimentally with a view to selecting from among them those which, while capable of doing the work required of them efficiently at a reasonable cost, and while possessing such qualities as to render them reasonably safe in transportation, storage, and use, were least liable to ignite the fire damp, or coal-dust-air mixture, or mine-gas-coal-dust-air mixture found in mines.

For this purpose it became necessary to have a chamber in which the gas and dust could be introduced, and the explosive fired, at will, and all the conditions of the experimental trials be known and under

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control. Beginning some 30 years ago, many kinds of chambers have been employed, from one made of boiler iron mounted on wheels used at Zwickau, Germany; an abandoned mine tunnel used at Rossitz, Austria; a wooden gallery used at Frameries, Belgium; a concrete gallery used at Lievin, France; to metal galleries as used at Woolwich, England, and Pittsburg, United States. This last is one of the most modern of these testing galleries, it having been erected on the arsenal grounds by the technologic branch of the United States Geological Survey in 1908, and as it was designed after careful study of the characteristics of different galleries abroad it may be regarded as representing the latest type of testing chamber.

This chamber, which is styled gas and dust gallery No. 1, is shown in plate 1. It consists of a cylinder 100 feet in length and 6⅓ feet in diameter, which is built of boiler-plate steel, in five divisions, each consisting of three sections 6⅔ feet long. The gallery is closed at one end by a concrete head. The different sections of the gallery are for convenience in operation numbered consecutively from 1 to 15, beginning with the section nearest the concrete head. Sections Nos. 1, 2, and 3 are made of one-half inch plates, the remaining sections of three-eighths inch plates, and all of steel having a tensile strength of not less than 55,000 pounds to the square inch. The sections are held together by lap joints, at each of which there is on the interior of the gallery a ring, formed of 2½-inch angle iron, upon the face of which paper diaphragms may be so secured as to partition off any desired portion of the gallery at will, and thus provide a closed space of any desired volume, within the capacity of the gallery, in which to inclose the gas-air, coal-dust-air, or gas-coal-dust-air mixture to be used in the test.

Each section is provided with a pressure-release door placed centrally on top, which not only provides a vent by which the gases may immediately escape after the explosion, and thus acts as a safety valve to prevent the destruction of the gallery, but also affords an approximate means of estimating the pressures developed. Each door closes on a rubber gasket and is provided with a rubber bumper on its back to prevent injury when thrown open violently. In use each door may be left open, or closed but not fastened, or closed and fastened, as seems best under the experimental conditions which obtain.

Each section is provided with a stout plate-glass window placed in the center of the section on the operating side of the gallery through which the progress of any flame produced in the gallery may be viewed and noted, while an indicator cock, tapped into the central section, provides a means by which samples of the mixtures in the gallery may be taken for analysis.

The gallery is so connected with the natural-gas supply used in Pittsburg that it may be filled with gas at will, and the quantity

GAS AND DUST GALLERY, NO. 1, PITTSBURG TESTING STATION.

BARRICADES AT MOUTH OF GALLERY.

EXPLOSION OF A MIXTURE OF COAL DUST AND AIR.

OBSERVATION ROOM.

charged is measured by a meter which can be read to one-twentieth of a cubic foot. The air and gas are mixed by means of circulating systems exterior to the gallery, operated by monogram exhausters. The circulating system for the first division is stationary and includes steam heating coils by which to bring the mixture in the gallery to a constant temperature. The remaining divisions of the gallery are served by a portable device.

When coal dust is to be used it is spread on a series of shelves, 20 feet long by 4 inches in width, lining the gallery, there being four of these on each side, and in addition upon a steel trestle, having a surface 20 feet by 12 inches, which is placed for that purpose in the first section of the gallery when coal dust is to be used. This dust is always freshly ground from lump coal to 100 mesh in fineness just before using.

In addition the gallery is provided with a humidifying apparatus provided with a Koerting exhauster, having a capacity of 240,000 cubic feet of free air per hour, by which the effect of moisture in preventing the propagation of explosions may be quantitatively ascertained.

The explosives to be tested may be suspended in the chamber and fired in the prepared atmosphere, and this method has been pursued at some stations, but the regular practice at the Pittsburg testing station is to fire the charge in a special "cannon," as this more nearly simulates the conditions in mining where the charge is fired in a bore hole in coal or rock. These "cannon" are cylinders 24 inches in diameter by 36 inches in length, with bore holes 2¼ inches in diameter by 21½ inches in depth. The simplest of them have been made in one piece from a low-carbon steel or nickel-steel forging. Others have been built up from centrally perforated jackets of cast steel, vanadium steel or other iron alloy, and a liner of nickel steel or other metals or alloys. In repairing, after erosion, the liner has been formed by the thermite process. No definite conclusions have yet been reached as to the relative merits of the different forms of construction. These "cannon" are shown in the right foreground of plates 2 and 4 and in the center of plate 6, figure 1.

The "cannon" is embedded in the concrete head of the gallery and is so laid that its axial line coincides with the axial line of the gallery. The "cannon" is loaded from within the gallery, but the charges are fired by electric detonators for high explosives and electric igniters for explosives of the gunpowder class, the firing machine being located in an observation room 60 feet distant from the gallery. The larger part of the explosives tested are detonated, and they are fired both stemmed and unstemmed into the sensitive mixtures.

As when the explosive mixtures in the gallery are fired the blast from the mouth of the gallery is very destructive in its effects, two

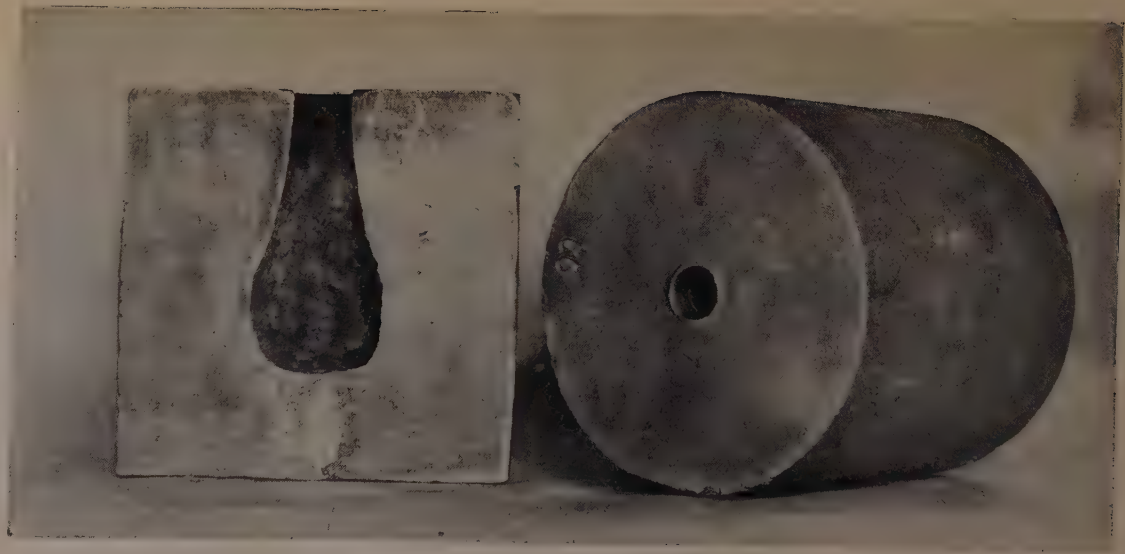
concrete barricades are erected on each side of the mouth of the gallery, and a thick iron plate is so suspended on a frame across, but at a distance of 50 feet from, the mouth of the gallery, that it may so swing as to deflect the blast and arrest any flying stemming or other material which may be blown out of the gallery. This arrangement is shown in plate 2, which also shows the reenforced-concrete foundation in which the gallery is set and specimens of the "cannon" used. The violence of the gallery explosions initiated by the charges of explosive used may be judged from plate 3, which is a photograph of an explosion of a coal-dust-air mixture.

The observation room from which the charge is fired and the visible phenomena occurring in the gallery observed is shown in plate 4. This room is 40 feet long by 9 feet 5 inches wide, built with brick walls 18 inches thick, and provided with a heavy plate-glass window, 37 feet long by 6 inches wide, which is protected by two projecting wooden guards. This room with its window is made so large in size that it may not only provide a large field of sight, but that it may accommodate a considerable number of persons, for the station is designed to be educational as well as experimental, and coal miners are brought there in large numbers to be convinced by experimental demonstrations of the accidents that may arise unless they use the explosives recommended by the station, and use them in the prescribed manner and amount.

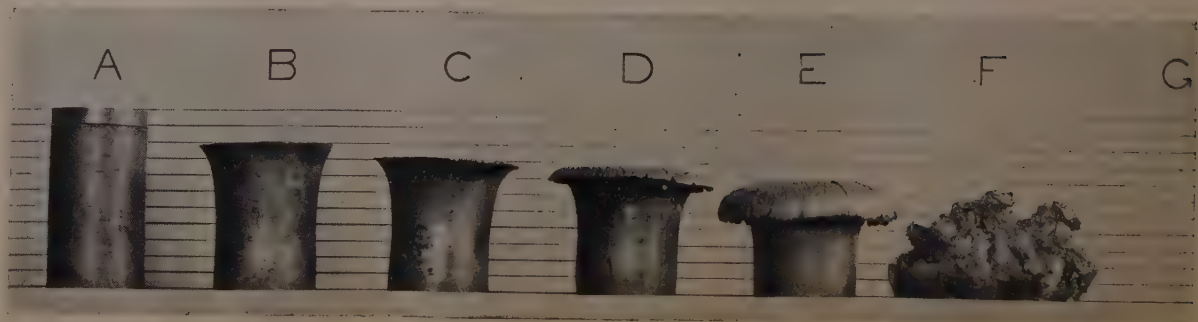
Prior to testing the explosives in the gallery, which is both costly and time consuming, they are subjected to other tests which may show them to possess such characteristics as to render them unfit for use and render the gallery test unnecessary. Thus they are inspected physically and analyzed chemically, and an admirably equipped and well-manned laboratory is provided for this purpose. Among other tests, the gravimetric density of the material, in the original package in which it would be used in the mine, is determined by the aid of dry sand as the mobile medium, and this density is carefully preserved in those tests in which density is a factor.

One of the first tests to be made is the determination of what is styled the "unit-disruptive charge," which is ascertained by the aid of the ballistic pendulum shown in plate 5. This apparatus consists essentially of two parts—the "cannon," in which the charge is fired, and the pendulum, which receives the impact of the products of the explosion, and that of the stemming when the latter is used. The "cannon" is identical in form, construction, and proportions with those used in the gallery. It is mounted on a four-wheeled truck, to which it is made fast by straps and rods. The truck runs on a 30-inch track which is provided with a recoil bumper placed 9 feet from the face of the pendulum mortar. The "cannon" is carefully placed axially in line with the pendulum mortar.

BALLISTIC PENDULUM.



1. TRAUZL TEST.



2. SMALL LEAD BLOCK TEST.

The pendulum consists of a 12.2-inch Army mortar, weighing 31,600 pounds, which rests in a stirrup made of two $1\frac{1}{2}$-inch machine-steel rods bent in a U shape. The ends of these rods pass through a solid-steel supporting beam and are held fast to it by cast-steel saddles fitting over the beam. This beam is provided with two nickel-steel knife-edges countersunk in its lower face, which rests on bearing plates provided with small groves that permit of the knife-edges being kept in oil, so as to be protected from the weather. The bearing plates rest on base plates which are anchored to the concrete piers between which the pendulum mortar swings.

The concrete piers are each 51 by 120 inches in dimension at their bases and 139 inches high. The outside walls taper, while the inside walls are vertical, and there is a clearance of 60 inches between these piers. A firing line, with a coupling box, is attached to the left-hand pier, and by its aid the firing may be done from a safe distance.

The extent to which the pendulum mortar is deflected is measured by a detachable device consisting of a graduated scale, with its vernier, which is set on a steel base fastened to a concrete footing below and to the rear of the mortar, the movable parts being actuated by a contact rod, set in guides, which bears at one end against a stud bolt in the bottom of the mortar directly below the point at which its center of gravity is located, and, at the other, on the scale. The radius of the swing of the pendulum mortar, measured from the knife-edge bearings to the center of the contact rod, or to the base of the stud bolt, is $114\frac{7}{16}$ inches. The radius of the swing, measured from the knife-edge bearings to the center of the trunnions of the mortar, is $89\frac{3}{4}$ inches. The recording device measures the deflection of the pendulum to within the one-hundredth part of an inch.

The standard used for this test is 227 grams (one-half pound) of 40 per cent straight dynamite, stemmed with 1 pound of dry clay, tamped with tamping sticks of standard pattern under a uniform rate of pressure, and fired with a No. 6 electric detonator. The unit-disruptive charge of another explosive is that weight of this explosive that will, when fired under the prescribed conditions, give the same deflection of the pendulum mortar as the standard dynamite charge does.

In making the test after the recording device is set, the "cannon" is loaded in the prescribed manner and rolled up to within one-sixteenth of an inch of the muzzle of the pendulum mortar, and stops are so placed that this distance is maintained when the flanges of the wheels of the truck are against them. The legs of the detonator are then connected to the firing line, and the party loading, who has also been carrying the safety plug with him, retires to the firing machine, inserts the safety plug, and fires.

Firing trials with the standard show that variables enter here, and that the same pendulum deflection is not invariably obtained with equal weights of charge of the standard dynamite, even though the successive charges are tamped in the "cannon" with the same degree of pressure, stemmed with the same weight of fire clay, and fired by the same numbered detonator. A condition affecting this result is the distance of the "cannon" from the mortar, and hence, as shown above, this distance has been definitely fixed. Another is the position of the knife-edges supporting the pendulum mortar, and to eliminate the effect of this the knife-edges are trammeled before each trial. Other factors affecting the results are the direction and velocity of the wind, the condition of the bore hole in the "cannon," and that of the person charging the "cannon." No one of these can be controlled absolutely. Hence, the explosive to be tested must be proved in this ballistic-pendulum test directly against the standard, both being handled and charged by the same person on the same day and as nearly as possible under the same conditions, for this tends to eliminate the personal equation, through its effects becoming nearly uniform, and to eliminate the effects of wind and weather, since they are fairly uniform during the trial periods. The condition of the bore hole is the existing variable factor which is the most difficult of elimination.

The energy of the explosive is further ascertained comparatively by the Trauzl and by the small lead-block tests. The device used in the Trauzl test is shown in plate 6, which consists of lead blocks 200 millimeters in diameter and 200 millimeters in height, in which holes 25 millimeters in diameter and 125 millimeters in depth are bored centrally in the top. These cylinders are cast from desilvered lead and all used in the same series of tests are carefully prepared under identical conditions and from the same melt. The volumes of these bore holes are carefully measured by means of water.

Ten grams of the explosive, weighed on a balance of precision, are wrapped in similar-sized pieces of tin foil, together with a No. 7 electric detonator, and the whole inserted in the bore hole of one of these cylinders, then 40 cubic centimeters of dry Michigan dune sand, of such fineness that it will all pass through a 50-mesh screen and be caught on an 80-mesh one, are poured into the bore hole and tamped 10 blows with an automatic tamping device, which operates on the principle of an automatic center punch, and delivers blows of known magnitude over a definite area. Then 10 cubic centimeters more of the same sand are poured in and tamped with 40 blows of the tamping device. The loaded cylinder is placed on a piece of heavy shafting imbedded in concrete, which forms a rigid support, the temperature of the block is ascertained to make sure that it is 15° C., and, when this is attained, the charge is fired. The cavity is again meas-

ured by calibration with water and the increase in volume produced by the charge of explosive fired is compared with that produced by an equal weight of the standard dynamite fired under the same conditions. The Trauzl test is quite widely used, and abroad it has been recommended that the cylinder be covered by a lead plate secured by a yoke. But it is found that in putting on the yoke the charge and stemming were disturbed and, as uniformity in these last particulars are of much more importance in these comparative tests than a greater degree of confinement, the plate and yoke are not recommended.

The Trauzl test measures comparatively the displacing effect of an explosive under moderate confinement. The small lead-block test measures comparatively the pressure exerted in contact by a charge of explosive which is detonated or exploded unconfined, or, in other words, the percussive effect. The blocks used and the deformations produced on some of them are shown in plate 6, figure 2. The lead blocks employed are cylinders 1½ inches in diameter and 2½ inches high. The charge of explosive used is 100 grams. Since an unconfined charge of high explosive, such as the standard dynamite, would, on detonation in contact, deform the cylinder beyond measurement, as shown by F in the figure, a disk of annealed steel 1½ inches in diameter and one-fourth inch in thickness is placed upon the lead cylinder. Since this plate retains a portion of the energy expended the compressed cylinders record only the residual energy.

In making the test, after placing the steel disk on the cylinder, a strip of manila paper is so secured about and beyond them as to provide a container, above the plate, for the explosive to be fired. The cylinder is then placed on a rigid support, the carefully weighed charge of explosive poured in and so tamped as to acquire the specific gravity it possessed in its original container, the No. 7 electric detonator inserted, and the charge fired. The height of the compressed cylinder is then ascertained with precision, and this comparison, as compared with that produced in a cylinder subjected to the detonation of 100 grams of the standard dynamite, is styled the relative percussive force of the explosive.

A more accurate idea of the pressures produced by an explosive may be obtained by means of the Bichel pressure gauge which is employed to determine the "maximum pressure of an explosive in its own volume," by which is meant the maximum pressure which an explosive exerts when exploded or detonated in a space which it fills completely, and when all of the heat set free through the chemical reactions taking place during the explosion are retained by the products of the reaction. Evidently this condition never actually obtains in practice, for a portion of this heat is always communicated to the walls of the inclosure. The portion thus lost from the products dif-

fers in amount with the temperature differences, with the rate at which the heat is set free in the reaction, with the materials of which the chambers are composed and the extent of the exposed surface in the chambers. Using chambers made of the same material it becomes possible, by varying the areas of these exposed surfaces in the different experiments to a known extent, to measure the heat-absorbing effect of surfaces of known area, and by combining this data with that recorded for the pressure, to ascertain the total dynamic effect of the charge of the explosive tested. This apparatus moreover affords a means by which the gaseous, liquid, and solid products of the reactions attending explosion may be collected for chemical analysis and physical inspection and study.

In plate 7 are shown two of these gauges, one of which is open and ready to load while the other is closed for firing. It will be observed that they are in principle like the bombs used by Noble and Abel in their Researches on Fired Gunpowder, but they are markedly developed in details of construction and in the addition of accessories. One of these cylinders has a chamber capacity of 15 liters, the other of 20 liters, but the volume of the latter may be reduced at will by inserting steel disks of known volume and area. The surface is thereby changed so that while the cooling surface of the small chamber is 3,914 square centimeters, that of the large cylinder, when one large steel disk is inclosed, is 6,555, and when three of the smaller disks are inclosed, 7,624 square centimeters.

These cylinders are made of steel 12.5 centimeters in thickness and the removable heads are secured in place by 12 heavy stud bolts, packed with lead washers, and an iron yoke. A system of sheaves and suspended counterweights is provided to aid in detaching the heavy heads from the cylinders and mounting them upon the specially designed wagons, so as to give ready access to the interiors of the cylinders.

Before the charge is fired the cylinders are exhausted to 10 millimeters of mercury. To permit of this being done a well-glanded tube is inserted in a perforation in an upper segment of each cylinder near one end, and this is provided with a valve by which to isolate the air pump after the vacuum has been attained. On the opposite upper segment of the cylinder from the exhaust a second opening is provided in which a glanded housing is inserted, which affords a means for introducing the electric detonator and so packing its legs as to prevent air entering about them while the cylinder is exhausted or gases escaping about them after the explosive has been fired and while a considerable pressure obtains within the cylinder.

A third perforation in the top of the segment carries a properly glanded tube provided with a piston 0.3937 centimeter in diameter, which can move up and down within this tube. This piston is held

on its seat by springs of known dimensions and effect. A stylus is mounted on the upper end of the stem of the piston in such manner that it moves freely only in the vertical plane, while the motor-driven drum at its rear, against which it impinges, rotates horizontally, thus producing a curve which, by its magnitudes and variations, records the extent of the pressures developed from the beginning to the end of the explosion.

The charge of explosive used varies from 100 to 200 grams, according to its character, as judged by the results of the chemical analysis which has been made of it. The explosive is removed from its original wrapper and inclosed in a wrapper of tinfoil in such manner as to preserve its original density. The head of the cylinder is removed, the No. 7 electric detonator passed through the glanded plug, and then inserted and secured in the cartridge, the fused cartridge laid on a small wire support in the center of the cylinder, the head replaced, the vacuum produced, the indicator drum set in revolution, and then, all parts being found secure and operative, the charge is fired and the indicator diagram taken. Three shots are made with each of the different cooling surfaces.

After the explosion the products are allowed to cool to the room temperature which, with the tension of the gases, the barometer and the volume of the cylinder, is noted and the volume of the gaseous and vaporous products is reduced to normal. A sample of these gases and vapors is then drawn out through the exhaust opening and analyzed. The liquid and solid products are recovered, measured, and analyzed after the head has been removed.

As is well recognized, the heat developed by an explosive when it explodes is one of the most important of the factors which determine its effect, and since Berthelot first employed the calorimetric bomb with which to directly measure the number of heat units set free by a known weight of an explosive, attention has been given to the improvement of this device so as to render it more useful. One of the modern forms of this instrument is Mettegang's explosion calorimeter, which is shown in plate 8.

This consists of a bottle-shaped calorimetric bomb 30 inches high, with a capacity of 30 liters, made of wrought steel one-half inch in thickness, and closed by a cap having an air-tight fit. Two holes are tapped into this bomb on opposite sides of the curvature of the neck, into one of which a valve is tapped by which to connect the bomb with an air pump, and into the other a plug through which the legs of the detonator are carried. This bomb when charged is placed in an immersion vessel, filled with a known weight of water, which is made of nickel-plated copper one-sixteenth inch in thickness, and which is strengthened by bands of copper wire wound about the outside. The immersion vessel is placed, with its contained

bomb, in a wooden-insulating vessel provided with a wooden cover. The accessories consist of a framework stirring device rotated or raised by an electric motor with which to bring the entire mass of water to a uniform temperature, a thermometer with open scale reading to one one-hundredth of a centigrade degree, a magnifying glass with which to read this thermometer, a pair of scales on which to accurately weigh the several parts of the system and the water that is used, a hocking frame to raise the vessels from the scales and deposit them in place, and a machine with which to fire the charge.

The water equivalent of the calorimeter having been determined and the effect of the detonator and tin-foil wrapping having been ascertained a charge of 100 grams of the explosive, wrapped in tin foil, is connected with a No. 7 electric detonator and suspended in the bomb, which is closed and exhausted down to 10 millimeters of mercury. The immersion vessel having received its weighed charge of water all the parts of the calorimeter are assembled and the stirring device set in motion to bring the water, and therefore all essential parts of the calorimeter, to a common temperature. When the thermometer immersed in the water shows that a constant temperature has been reached the charge is fired and the rise in temperature recorded on the thermometer carefully observed until the mercury has reached its greatest altitude in this experiment. From this data, together with that referred to above, the number of calories given by a known weight of the explosive is found.

In firing by dentonation it is essential for safety and success in blasting that when the reaction is once initiated by the detonator it shall proceed throughout the column of explosive for otherwise a portion of the charge may be thrown out of the bore hole unexploded but inflamed, producing a "blown-out shot" which may ignite the fire damp or coal-dust-air mixture, or a portion may be left in the bore hole unexploded where it constitutes a source of danger in subsequent operations, or it may be brought down mixed with the coal to produce trouble in the breakers, in transportation, or in the use of the coal. The test employed to ascertain the relative sensitiveness of explosives to the detonation of masses of their own kind is called the explosion by influence test. I have applied this term to the testing of explosives for their sensitiveness to the initial detonation of a standard explosive, and described the method in the Journal of the American Chemical Society 15, 10–18; 1893. A commercial method now used for some time is one in which the cartridges are placed in rows on the ground, or other support, with spaces between each, and varying the intervals between the cartridges in successive trials. A more modern and severer test is to so bind two cartridges together with wire that they may be suspended vertically in the air, end to end, at a carefully measured distance apart, a

detonator, of the grade recommended by the manufacturer of the explosive, being inserted in the lower end of the lower cartridge, secured in place, and fired. By proceeding tentatively the distance at which detonation by influence ceases is said to be established within very narrow limits. For comparison between different explosives cartridges of uniform size are used, such as 1¼ inches in diameter by 8 inches in length. This may necessitate the repacking of the explosive, and when this is done care should be taken to preserve the original density, since this is a factor in this behavior of explosives.

While the explosive should be sufficiently susceptible to detonation to be fired with certainty it should not be so sensitive to percussion as to be dangerous in handling, transportation, or use. This sensitiveness of explosives to the effect of direct blows is determined by the impact machine shown in plate 9, which consists of a vertical steel framework carrying two guide rods between which a yoke, to which the impact weight or hammer is attached, is guided; an anvil upon which the charge of explosive is placed; and a soft-steel plunger which rests upon the anvil and upon which the hammer impinges in its fall. The yoke is provided with jaws which engage the lugs of an endless chain moving behind it, and by this mechanism the yoke with its attached weight is raised to any desired height. By means of an electric current the yoke may be magnetized and demagnetized at will so that when magnetized it will attract and support the hammer to such an extent that both may be raised together by the endless chain to any predetermined height, at which point the yoke is demagnetized, the hammer or weight is released and the latter then falls through the intervening distance and impinges upon the plunger. The stop which arrests the upward travel of the magnetized yoke and automatically causes its demagnetization is operated by a vertically driven precision screw on the right-hand side of the frame, which is also geared to a recording device which measures the height from which the hammer falls. By the aid of this screw and its accessories one is able to set the stop in advance so as to secure any desired distance of fall for the hammer within the capacity of the machine.

The hard-steel anvil is set firmly on a heavy iron base and it is surrounded by a tubulated jacket through which water may be circulated, so as to bring the temperature of the anvil and of the charge of explosive placed upon it to any desired temperature and to keep it there. The plunger is held lightly in place by a steel guide which forms a part of the base support for the vertical-guide rods. It is essential that the faces of the plunger and of the anvil which are in contact should be absolutely true and plane. As the impacts and explosions produce deformation of the metal, the plunger is made of

soft steel, so that the deformation may accumulate on it, and therefore it is very frequently turned up on a lathe and reground to true up its face.

The hammer used weighs 2,000 grams. The soft-steel plunger weighs 900 grams, and the maximum height from which the hammer can be dropped is 100 centimeters. The weight of charge of explosive used is 0.02 gram. The temperature of the anvil and the explosive at the time of testing is 25° C.

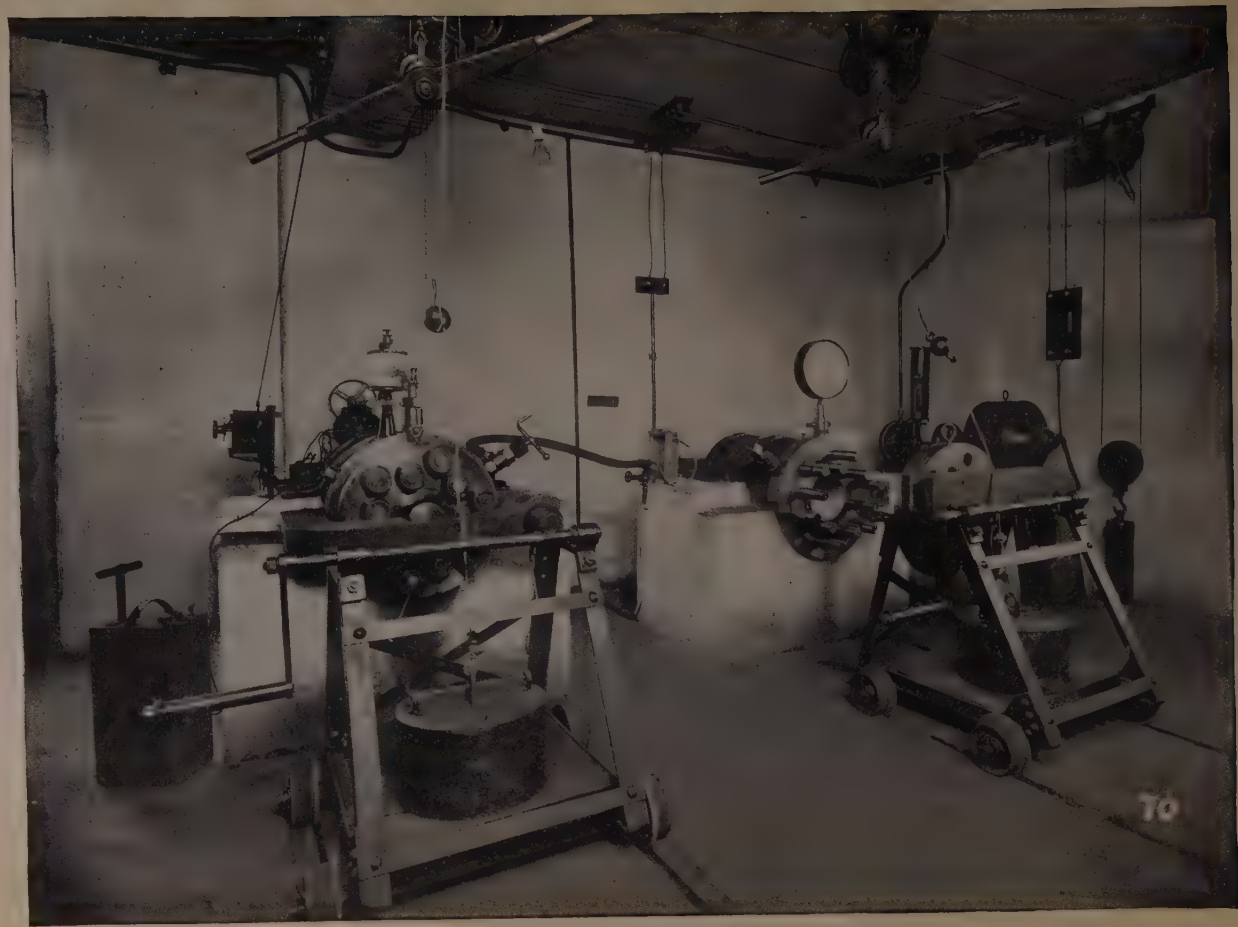
In making the test the explosive is weighed out on a chemical balance and the charge so wrapped in tin foil as to make a pellet in the form of a flat disk 1 centimeter in diameter. The hammer is raised, the stamp is lifted, the pellet is placed on the anvil, the stamp is pressed gently down upon it, so as to insure a good contact, and the whole is left to attain the standard temperature. The stop is then set by judgment and the hammer raised until it is disengaged at the chosen height and falls upon the plunger. If no explosion ensues, the stop is set at a greater height and the hammer released, and this method of procedure is repeated until either explosion occurs on impact or the maximum range of the machine is reached. When explosion does occur the test is repeated with a fresh charge of explosive and slightly diminished distance of fall, and one thus proceeds tentatively until such a height of fall for the hammer is reached that there is no explosion, and yet if that height be exceeded by but 1 centimeter an explosion occurs. This point is then fixed by four additional tests, giving the same results.

Provided all other conditions remain the same the brisant or shattering effect of an explosive varies with the velocity with which the chemical reaction, or explosion wave travels through the column or charge of the explosive. Where explosives are fired by detonation this movement, as measured in definite terms of time and length, is styled the rate of detonation of the explosive. The making of such determinations is not new, for Abel measured the rate of detonation in guncotton, nitroglycerine, and dynamite nearly 40 years ago,[1] and Berthelot did so some 10 years later.[2] What has been done in recent years has been rather in the standardizing of the method, the improvement in the details and operation of the chronograph, and the introduction of the method into general practice.

To assure a definite and uniform area of exposure, the cartridges of explosives in their original wrappers, but with the ends cut off so as to avoid the damping effect of the layers of paper, are packed in tubes of thin sheet iron 42 inches in length and varying in diameter from 1½ to 2 inches, according to the character of the explosive to be tested. When the tube has been charged two copper

[1] Phil. Trans. 164, 377; 1874.

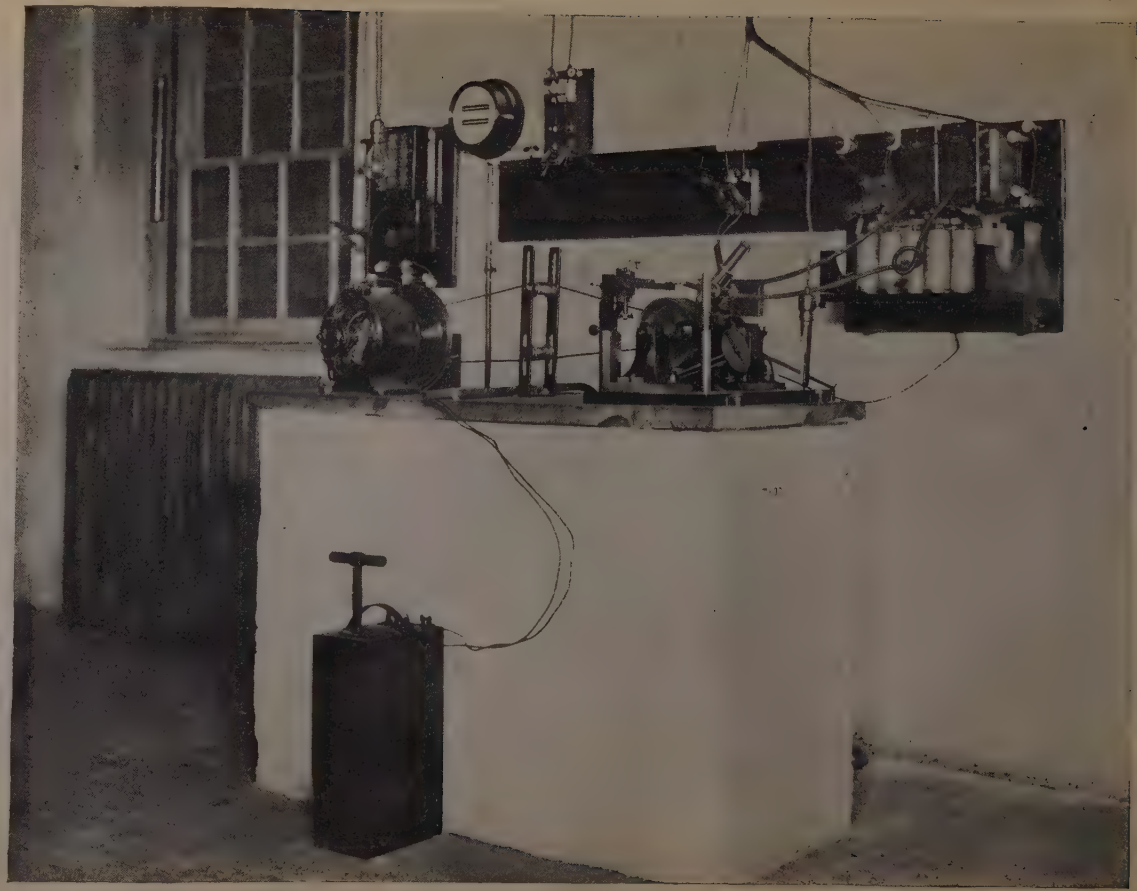
[2] Ann. chim. phys. (6) 6, 556.



BICHEL'S PRESSURE GAGES.

METTEGANG'S EXPLOSION CALORIMETER.

IMPACT MACHINE.



MATTEGANG RECORDER.

wires are inserted through perforations in the tube and the cartridge file at a distance of 1 meter apart, and these wires are separately led to a chronograph. An electric detonator of the usual type and grade is inserted in one of the end cartridges of the file; the tube, as now arranged, is suspended in the firing chamber; the copper wires which pass through the explosive are connected up to the chronograph; and the charge is fired.

The chronograph which records the time that elapses between the rupturing of the wire nearest the detonator and the wire 1 meter distant from it is known as a Mettegang recorder, and is shown in plate 10. The primary components of the Mettegang recorder are a soot-covered bronze drum so connected to an electric motor that it may be caused to revolve at any desired speed up to 105 revolutions per second; a 200-volt D. C. electric motor provided with a rheostat for controlling its speed; a vibration tachometer so connected to the bronze drum that the number of revolutions of the latter in unit of time are accurately measured for any speed between 50 and 105 revolutions per second; induction coils which may receive their electric current from electric-lighting circuits having terminal pressures of from about 110 to 220 volts; and platinum terminals placed about one-fourth of a millimeter from the surface of the rotating drum, and in circuit with the induction coils, by which electric sparks are so projected against the surface of the drum as to disturb its sooty covering and produce a tiny bright spot at the point of impact, which spot may be easily perceived by the aid of a microscope attached to the drum.

The drum is 500 millimeters in circumference. The edge of this drum is provided with 500 teeth which may be made to engage an endless screw. A pointer attached to this screw passes over a dial reading to hundredths, and it thus enables one to read the distance intervening between the spots produced on the soot-covered surface of the drum with great precision. The drum is provided with six platinum terminals which are held by an insulated arm that may be so moved as to bring the points within any desired distance from the drum, and each one of these points may be put in series with one of the induction coils while the other end of the electric lead is grounded to the drum through the base which supports it. Only two of these platinum terminals are used in any single-firing trial for the determination of the rate of detonation in a given explosive, while the other four are held in reserve for future use.

To operate this method of ascertaining the rate at which detonation when once initiated is transmitted through a column, or file, of an explosive, the electric current which is used as the medium for transmitting the record is, as taken from its source, divided into two

parts by passing it through two equal lamp resistances, each of which, at the Pittsburg testing station, consists of a series of five 16-candle-power lamps. These leads are then, after independently traversing the cartridge file at the initial and final points, jointly connected to one of the poles of the primary coil of the induction coil through which the current passes to the return conductor. The secondary coil of the induction coil is then connected by one pole to the two platinum terminals and by the other pole to the base supporting the drum as described. As is well known, in the induction coil any change of tension in the primary coil sets up an induced current in the secondary coil, and this mutual induction between the coils results in the production of a higher potential difference at the terminals of the secondary one so that sparks of considerable length and intensity may be obtained.

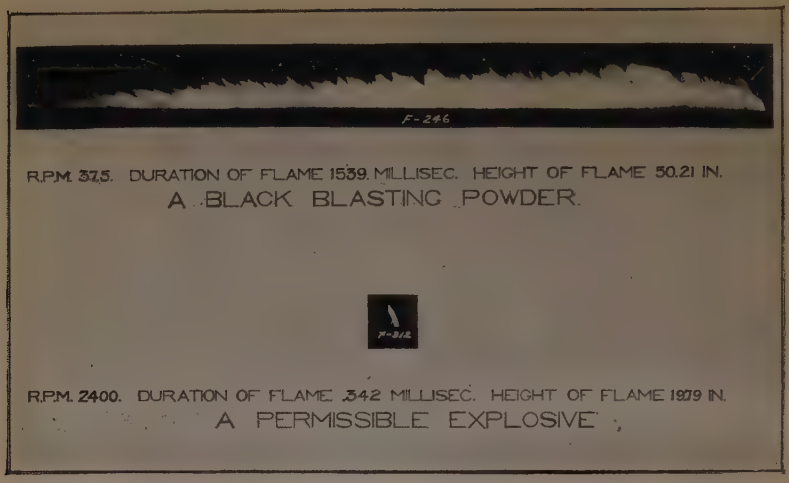
The vibration tachometer, by which the speed of rotation of the drum is measured, is connected to an auxiliary shaft which engages the main shaft of the drum by gears, thus preventing any irregularity in recording the speed due to slipping. This tachometer measures the number of rotations of the drum, and as the circumference of the drum is accurately known, the distance which any point on the periphery travels may easily be calculated. Hence, at the highest speed of 105 revolutions per second, the distance of travel is 52.5 meters. At 50 revolutions it is 25 meters. At 86 revolutions it is 43 meters per second. With this number of revolutions it is possible with this instrument to measure the one-four-million-three-hundred-thousandth part of a second of time.

A more recent and simpler method of measuring the rate of detonation is that devised by M. d'Autriche,[1] which was described at the congress in London, in 1909, by Dr. A. M. Comey, as follows:

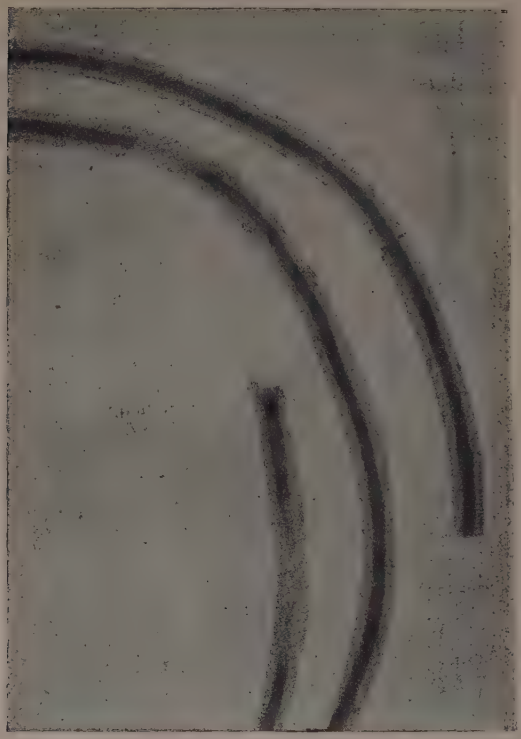
The method of M. d'Autriche depends upon the use of a special detonating fuse having a uniform velocity of 6,000 meters per second. A suitable length of fuse, according to the length of the column of explosive to be tested is taken for the test and the exact middle of the fuse is determined by measurement and marked. A fulminate cap containing a charge of 15 grains (1 gram) is slipped over each end of the fuse and crimped securely. The fuse is then laid upon a piece of 32-pound sheet lead (1½ inches by 15 inches by ½ inch) (38 by 380 by 13 millimeters), so that the center of the fuse is about in the center of the sheet of lead, and the point coinciding with the middle point of the fuse is marked plainly on the sheet lead (M). The fuse passes along the entire length of the sheet of lead, and its ends are bent around so that they nearly meet. The two ends of the fuse covered with the detonating caps are inserted a short distance, at two points, into the column of explosive, the velocity of which is to be tested, and the distance between these points accurately measured. This may be called (A). A fulminate cap with fuse or electric connections is placed in one end of the stick of explosive. When this cap is detonated, the explosive wave proceeds through the detonating fuse in both directions and meets at a point

[1] Comptes rend. *143*, 641 and *144*, 1030.

FLAME TEST APPARATUS.



1. FLAMES FROM EXPLOSIVES.



2. X-RAY PHOTO OF FUSE.

(T) where a sharp line is formed by the effects of the detonation itself, and the lead is often broken through at this point. The distance from (M) to (T) is accurately measured and designated as (b). If the two ends of the fuse are detonated simultaneously (M) and (T) fall together; that is, the detonation proceeds at the same rate through the two halves of the fuse and meets at the middle, but when a certain length of an explosive is placed in the circuit we have on one side one-half the length of the fuse and on the other side one-half the length of the fuse plus a certain measured length of explosive. We have thus, letting—

X=Velocity of detonation of the explosive tested.
V=Known velocity of the fuse (6,000 meters per second).
A=Distance between two ends of fuse, or length of explosive tested.
b=Distance between M and T.

Then,—

$$X=\frac{VA}{2b} \text{ or } \frac{6000A}{2b}.$$

As to the accuracy of the test, it was found that by using the fuse alone (M) and (T) always coincided to within one-eighth of an inch (3 millimeters). It is easily seen that errors in measurement will be diminished by increase in the length of explosive tested, and it can be calculated, with velocities of 4,000 to 6,000 meters per second, using 15 inches (38 centimeters) of powder, that an error of one-fourth of an inch (6 millimeters) in measurement of the distance (M) to (T), which is a very large one under the conditions, introduces an error in the determination of the velocity of about 5 per cent.

Comey and his associates have tested this method quite fully at the eastern laboratory of the Du Pont Powder Co., and have found that it gives not only a ready and accurate means of determining the velocity of detonation through a column of any desired length of explosive, but that it is also possible by this method to determine the velocity with which a detonation wave travels through the air.

It is obvious that the flame-giving qualities of an explosive plays a most important part in its liability to ignite fire damp and other combustible mixtures, and that, all other conditions being equal, that explosive which gives the shortest flame for the briefest time is most suitable for use. Hence latterly much attention has been given to the study of the flames from explosives, and many devices have been constructed by which to photograph them.

Among these is the one employed at the Pittsburg testing station, where the flame is photographed on a moving film. The charge of explosive is fired from a "cannon" of the type used in the gallery tests by means of an electric detonator or igniter, but in this test the "cannon" is mounted vertically in a concrete foundation at a distance of about 18 feet from the lens of the camera. To cut off extraneous light rays, so that the tests may be made at any time, the "cannon" is inclosed in an iron cylinder 20 feet in height and 43 inches in diameter, which is connected with the dark room by a light-tight iron conduit, as shown in plate 11. The cylinder, or

stack, is provided with a door in the side, through which the "cannon" can be loaded, and with a vertical slit 8 feet in length by 2 inches in width, which is so placed that its vertical center coincides with that of the conduit and also with that of the lens by which it is viewed. At the time of firing the top of the stack is covered with black paper. The conduit is closed at the point where it ends in the wall of the dark room by a shutter.

The camera consists of a drum on which the sensitized film is mounted, an electric motor by which the drum is revolved at a known rate, a quartz lens, a semicircular shield in which a stenopaic slit has been cut, and a shutter by which to control the slit in the shield. All of these except the motor are inclosed in a light-tight box. The semicircular shield is placed close to and concentric with the drum to prevent any light reaching the film except that passing through the stenopaic slit. A lens of quartz is used because it focuses not only the visible light rays, but also those invisible violet rays which occur to a large extent in the flames from explosives.

By means of a tachometer both the number of revolutions per minute of the motor and the peripheral speed of the drum are directly read off. The maximum peripheral speed of the drum is 20 meters per second, and this rate is employed when detonating explosives are tested, but with slow-burning explosives the drum is run at a slower rate. At the 20-meter rate 1 millimeter width of flame equals 0.05 millisecond of time, and as the measurements of the flame photographs are read to the nearest quarter of a millimeter the smallest time interval measured is the 0.0125 millisecond. The charge of explosive used in the test is 100 grams, and these charges are fired both with and without stemming.

The result of this test on black blasting powder and on a permissible explosive are shown in plate 12, figure 1. By the term "permissible explosive" is meant an explosive which has satisfactorily passed all the prescribed tests at the Pittsburg testing station and is regarded as suitable for use in coal mines.

One of the most novel of modern tests is that devised by J. Thomas,[1] who has employed the X rays for ascertaining the condition of the powder core in Bickford or running fuse. The cause of misfires and delayed ignitions has been the subject of much speculation, and among other theories proposed was that of a break in the continuity of the powder cores. In plate 12, figure 2, which is a copy of Thomas's X-ray picture, the interruption of continuity in two pieces of the fuse shown is very apparent.

[1] J. Chem. Met. Soc. S. Africa 9, 183; 1908.

SIR WILLIAM HUGGINS, 1824–1910.

SIR WILLIAM HUGGINS, K. C. B., O. M.[1]

[With 1 plate.]

By W. W. Campbell.

The name of Sir William Huggins is intimately associated with the entire history of astronomical spectroscopy. With Rutherfurd, Secchi, Ångström, Draper, and others, he was a pioneer in this subject; and by virtue of long life, enthusiasm, and uncommon wisdom, his contributions have enriched astronomical knowledge during a full half century. His lamented death on May 12, 1910, at the ripe age of 86 years, calls for a review of his remarkable career.

William Huggins was born in London on February 7, 1824. His father was in commercial life, and was able to provide the son not only with a good education, but the financial means to follow astronomy in a private capacity, unattached to university or established observatory. His early education was received in the City of London School, and he later studied the languages, mathematics, and various branches of science extensively under private tutors. Astronomy and microscopy were subjects of special interest, and it was a difficult question with him as to which he should attempt to advance through original investigations. The decision was made in favor of astronomy. In 1856 he removed to 90 Upper Tulse Hill, then a short distance in the open country south of London, now within the great city, where he erected an observatory in connection with his dwelling house; and there all of his work was done. "It consisted of a dome 12 feet in diameter and a transit room. There was erected in it an equatorially mounted telescope by Dolland of 5 inches aperture, at that time looked upon as a large rather than a small instrument." He commenced work on the usual lines, taking transits, observing the planets, and making drawings of planets. In 1858 the 5-inch refractor was replaced by a Clark 8-inch refractor of great excellence.

[1] Reprinted by permission after author's revision from publications of the Astronomical Society of the Pacific, vol. 22, No. 133, San Francisco, October, 1910.

In the Nineteenth Century Review for June, 1897, Sir William has given an interesting account of his entry into the spectroscopic field:

I soon became a little dissatisfied with the routine character of ordinary astronomical work, and in a vague way sought about in my mind for the possibility of research upon the heavens in a new direction or by new methods. It was just at this time, when a vague longing after newer methods of observation for attacking many of the problems of the heavenly bodies filled my mind, that the news reached me of Kirchhoff's great discovery of the true nature and the chemical constitution of the sun from his interpretation of the Fraunhofer lines.

This news was to me like the coming upon a spring of water in a dry and thirsty land. Here at last presented itself the very order of work for which in an indefinite way I was looking—namely, to extend his novel methods of research upon the sun to the other heavenly bodies. A feeling as of inspiration seized me. I felt as if I had it now in my power to lift a veil which had never before been lifted; as if a key had been put into my hands which would unlock a door which had been regarded as forever closed to man—the veil and door behind which lay the unknown mystery of the true nature of the heavenly bodies. This was especially work for which I was to a great extent prepared, from being already familiar with the chief methods of chemical and physical research.

It was just at this time that I happened to meet at a soirée of the pharmaceutical society, where spectroscopes were shown, my friend and neighbor, Dr. W. Allen Miller, professor of chemistry at King's College, who had already worked much on chemical spectroscopy. A sudden impulse seized me to suggest to him that we should return home together. On our way home I told him of what was in my mind and asked him to join me in the attempt I was about to make, to apply Kirchhoff's methods to the stars. At first, from consideration of the great relative faintness of the stars, and the great delicacy of the work from the earth's motion, even with the aid of a clockwork, he hesitated as to the probability of our success. Finally he agreed to come to my observatory on the first fine evening for some preliminary experiments as to what we might expect to do upon the stars.

* * * From the sun, with which the Heidelberg professors had to do—which, even bright as it is, for some parts of the spectrum has no light to spare—to the brightest stars is a very far cry. The light received at the earth from a first magnitude star, as Vega, is only about the one-forty-thousand-millionth part of that received from the sun.

Fortunately, as the stars are too far off to show a true disk, it is possible to concentrate all the light received from the star upon a large mirror or object glass, into the telescopic image, and so increase its brightness.

We could not make use of the easy method adopted by Fraunhofer of placing a prism before the object glass, for we needed a terrestrial spectrum, taken under the same conditions, for the interpretation, by a simultaneous comparison with it of the star's spectrum. Kirchhoff's method required that the image of a star should be thrown upon a narrow slit simultaneously with the light from a flame or from an electric spark.

These conditions made it necessary to attach a spectroscope to the eye end of the telescope, so that it would be carried with it, with its slit in the focal plane. Then, by means of a small reflecting prism placed before one half of the slit, light from a terrestrial source at the side of the telescope could be

sent into the instrument, together with the star's light, and so form a spectrum by the side of the stellar spectrum for convenient comparison with it.

This was not all. As the telescopic image of a star is a point, its spectrum will be a narrow line of light without appreciable breadth. Now, for the observation either of dark or of bright lines across the spectrum a certain breadth is absolutely needful. To get breadth, the point-like image of the star must be broadened out.

As light is of first importance, it was desirable to broaden the star's image only in the one direction necessary to give breadth to the spectrum; or, in other words, to convert the stellar point into a short line of light. Such an enlargement in one direction only could be given by the device, first employed by Fraunhofer himself, of a lens convex or concave in one direction only, and flat, and so having no action on the light in a direction at right angles to the former one. * * *

It is scarcely possible at the present day, when all these points are as familiar as household words, for any astronomer to realize the large amount of time and labor which had to be devoted to the successful construction of the first star spectroscope. Especially was it difficult to provide for the satisfactory introduction of the light for the comparison spectrum. We soon found, to our dismay, how easily the comparison lines might become instrumentally shifted, and so be no longer strictly fiducial. As a test we used the solar lines as reflected to us from the moon—a test of more than sufficient delicacy with the resolving power at our command.

Then it was that an astronomical observatory began, for the first time, to take on the appearance of a laboratory. Primary batteries, giving forth noxious gases, were arranged outside one of the windows; a large induction coil stood mounted on a stand on wheels so as to follow the positions of the eye end of the telescope, together with a battery of several Leyden jars; shelves with Bunsen burners, vacuum tubes, and bottles of chemicals, especially of specimens of pure metals, lined its walls.

In 1870 my observatory was enlarged from a dome of 12 feet in diameter to a drum having a diameter of 18 feet. This alteration had been made for the reception of a larger telescope made by Sir Howard Grubb, at the expense of a legacy to the Royal Society, and which was placed in my hands on loan by that society. This instrument was furnished with two telescopes, an achromatic of 15 inches aperture and a Cassegrain of 18 inches aperture, with mirrors of speculum metal. At this time one only of these telescopes could be in use at a time. Later on, in 1882, by a device which occurred to me of giving each telescope an independent declination axis, the one working within the other, both telescopes could remain together on the equatorial mounting, and be equally ready for use.

* * * It is not easy for men of the present generation, familiar with the knowledge which the new methods of research of which I am about to speak have revealed to us, to put themselves back a generation, into the position of the scientific thought which existed on these subjects in the early years of the Queen's reign. At that time any knowledge of the chemical nature and of the physics of the heavenly bodies was regarded as not only impossible of attainment by any method of direct observation, but as, indeed, lying altogether outside the limitations imposed upon man by his senses, and by the fixity of his position upon the earth.

It could never be, it was confidently thought, more than a matter of presumption, whether even the matter of the sun, and much less that of the stars, were of the same nature as that of the earth, and the unceasing energy

radiated from it due to such matter at a high temperature. The nebular hypothesis of Laplace at the end of the last century required, indeed, that matter similar to that of the earth should exist throughout the solar system; but then this hypothesis itself needed for its full confirmation the independent and direct observation that the solar matter was terrestrial in its nature. This theoretical probability in the case of the sun vanished almost into thin air when the attempt was made to extend it to the stellar hosts; for it might well be urged that in those immensely distant regions an original difference of the primordial stuff as well as other conditions of condensation were present, giving rise to groups of substances which have but little analogy with those of our earthly chemistry. * * *

The dark lines were described first by Wollaston in 1792, who strangely associated them with the boundaries of the spectral colors, and so turned contemporary thought away from the direction in which lay their true significance. It was left to Fraunhofer in 1815, by whose name the dark lines are still known, not only to map some 600 of them, but also to discover similar lines, but differently arranged, in several stars. Further, he found that a pair of dark lines in the solar spectrum appeared to correspond in their position in the spectrum, and in their distance from each other, to a pair of bright lines which were nearly always present in terrestrial flames. This last observation contained the key to the interpretation of the dark lines as a code of symbols, but Fraunhofer failed to use it; and the birth of astrophysics was delayed. An observation by Forbes at the eclipse of 1836 led thought away from the suggestive experiments of Fraunhofer; so that in the very year of the Queen's accession the knowledge of the time had to be summed up by Mrs. Somerville in the negation: "We are still ignorant of the cause of these rayless bands."

Later on the revelation came more or less fully to many minds. Foucault, Balfour, Stewart, Ångström prepared the way. Prophetic guesses were made by Stokes and by Lord Kelvin. But it was Kirchhoff who, in 1859, first fully developed the true significance of the dark lines; and by his joint work with Bunsen on the solar spectrum proved beyond all question that the dark lines in the spectrum of the sun are produced by the absorption of the vapors of the same substances, which when suitably heated give out corresponding bright lines; and, further, that many of the solar absorbing vapors are those of substances found upon the earth. The new astronomy was born.

Soon after the close of 1862, in collaboration with Dr. W. A. Miller, I sent a preliminary note to the Royal Society, "On the lines of some of the fixed stars," in which we gave diagrams of the spectra of Sirius, Betelgeux, and Aldebaran, with the statement that we had observed the spectra of some 40 stars, and also the spectra of the planets Jupiter and Mars. It was a little remarkable that on the same day on which our paper was to be read, but some little time after it had been sent in, news arrived there from America that similar observations on some of the stars had been made by Mr. Rutherford. A very little later similar work on the spectra of the stars was undertaken in Rome by Secchi and in Germany by Vogel.

In February, 1863, the strictly astronomical character of the observatory was further encroached upon by the erection, in one corner, of a small photographic tent furnished with baths and other appliances for the wet collodion process. We obtained photographs, indeed, of the spectra of Sirius and Capella; but from want of steadiness and more perfect adjustment of the instruments, the spectra, though defined at the edges, did not show the dark lines as we expected. The dry collodion plates then available were not rapid enough; and the wet process was so inconvenient for long exposures, from irregular drying, and

draining back from the positions in which the plates had often to be put, that we did not persevere in our attempts to photograph the stellar spectra. I resumed them with success in 1875, as we shall see further on.

Whenever the nights were fine, our work on the spectra of the stars went on, and the results were communicated to the Royal Society in April, 1864; after which Dr. Miller had not sufficient leisure to continue working with me.

* * * I pass on at once, therefore, to the year 1876, in which, by the aid of the new dry plates, with gelatin films, introduced by Mr. Kennett, I was able to take up again, and this time with success, the photography of the spectra of the stars, of my early attempts at which I have already spoken.

By this time I had the great happiness of having secured an able and enthusiastic assistant by my marriage in 1875.

The great and notable advances in astronomical methods and discoveries by means of photography, since 1875, are due almost entirely to the great advantages which the gelatin dry plate possesses for use in the observatory over the process of Daguerre, and even over that of wet collodion. The silver-bromide gelatin plate, which I was the first, I believe, to use for photographing the spectra of stars, except for its grained texture, meets the need of the astronomer at all points. This plate possesses extreme sensitiveness; it is always ready for use; it can be placed in any position; it can be exposed for hours; lastly, immediate development is not necessary, and for this reason, as I soon found to be necessary in this climate, it can be exposed again to the same object on succeeding nights; and so make up by successive installments, as the weather may permit, the total long exposure which may be needful.

The power of the eye falls off as the spectrum extends beyond the blue, and soon fails altogether. There is, therefore, no drawback to the use of glass for the prisms and lenses of a visual spectroscope. But while the sensitiveness of a photographic plate is not similarly limited, glass, like the eye, is imperfectly transparent, and soon becomes opaque, to the parts of the spectrum at a short distance beyond the limit of the visible spectrum. To obtain, therefore, upon the plate a spectrum complete at the blue end of stellar light, it was necessary to avoid glass and to employ instead Iceland spar and rock crystal, which are transparent up to the limit of the ultra-violet light which can reach us through our atmosphere. Such a spectroscope was constructed and fixed with its slit at the focus of the great speculum of the Cassegrain telescope.

How was the image of a star to be easily brought, and then kept, for an hour, or even for many hours, precisely at one place on a slit so narrow as about the one two-hundredth of an inch? For this purpose the very convenient device was adopted of making the slit-plates of highly polished metal, so as to form a divided mirror, in which the reflected image of a star could be observed from the eye end of the telescope by means of a small telescope fixed within the central hole of the great mirror. A photograph of the spectrum of α Lyræ, taken with this instrument, was shown at the Royal Society in 1876.

In the spectra of such stars as Sirius and Vega, there came out in the ultra-violet region, which up to that time had remained unexplored, the completion of a grand rhythmical group of strong dark lines, of which the well-known hydrogen lines in the visible region form the lower members. Terrestrial chemistry became enriched with a more complete knowledge of the spectrum of hydrogen from the stars. Shortly afterwards, Cornu succeeded in photographing a similar spectrum in his laboratory from earthly hydrogen.

The years 1863 to 1890 were made fruitful by Huggins, especially in the comparison of terrestrial and stellar spectra. He established that the principal elements in the earth's surface strata exist also in the atmospheres of the stars in the form of vapors and gases. Other studies attempted to arrange the principal stars in the order of their evolutionary history—in the order of their effective ages—from the different appearances of the hydrogen and metallic lines in their spectra.

Huggins's observation of the spectrum of a nebula, for the first time in 1864, has probably never been surpassed in dramatic interest in any department of science. From the days of Sir William Herschel it had been a much-discussed question whether the nebulæ—the faintly shining bodies which had not been resolved into separate star images—were continuous in structure like a great gaseous cloud, or were composed of stars unresolvable on account of their enormous distances. To let Huggins speak:

The nature of these mysterious bodies was still an unread riddle. Toward the end of the last century the elder Herschel, from his observations at Slough, came very near suggesting what is doubtless the true nature and, place in the cosmos, of the nebulæ. I will let him speak in his own words:

"A shining fluid of a nature unknown to us.

"What a field of novelty is here opened to our conceptions! * * * We may now explain that very extensive nebulosity, expanded over more than 60° of the heavens, about the constellation of Orion, a luminous matter accounting much better for it than clustering stars at a distance. * * *

"If this matter is self-luminous it seems more fit to produce a star by its condensation than to depend on the star for its existence."

This view of the nebulæ as parts of a fiery mist out of which the heavens had been slowly fashioned, began, a little before the middle of the present century, at least in many minds, to give way before the revelations of the giant telescopes which had come into use, and especially of the telescope, 6 feet in diameter, constructed by the late Earl of Rosse at a cost of not less than £12,000.

Nebula after nebula yielded, being resolved apparently into innumerable stars, as the optical power was increased; and so the opinion began to gain ground that all nebulæ may be capable of resolution into stars. According to this view, nebulæ would have to be regarded, not as early stages of an evolutional progress, but rather as stellar galaxies already formed, external to our system—cosmical "sandheaps"—too remote to be separated into their component stars. Lord Rosse himself was careful to point out that it would be unsafe from his observations to conclude that all nebulosity is but the glare of stars too remote to be resolved by our instruments. In 1858 Herbert Spencer showed clearly that, notwithstanding the Parsonstown revelations, the evidence from the observation of nebulæ up to that time was really in favor of their being early stages of an evolutional progression.

On the evening of August 29, 1864, I directed my telescope for the first time to a planetary nebula in Draco. The reader may now be able to picture to himself to some extent the feeling of excited suspense, mingled with a degree of awe, with which, after a few minutes of hesitation, I put my eye to the spectroscope. Was I not about to look into a secret place of creation?

I looked into the spectroscope. No spectrum such as I expected. A single bright line only. At first I suspected some displacement of the prism, and that I was looking at a reflection of the illuminated slit from one of its faces. This thought was scarcely more than momentary. Then the true interpretation flashed upon me. The light of the nebula was monochromatic, and so, unlike any other light I had as yet subjected to prismatic examination, could not be extended out to form a complete spectrum. After passing through the two prisms it remained concentrated into a single bright line, having a width corresponding to the width of the slit, and occupying in the instrument a position at that part of the spectrum to which its light belongs in refrangibility. A little closer looking showed two other bright lines on the side toward the blue, all the three lines being separated by intervals relatively dark.

The riddle of nebulæ was solved. The answer, which had come to us in the light itself, read: Not an aggregation of stars, but a luminous gas. Stars after the order of our own sun, and of the brighter stars, would give a different spectrum; the light of this nebula had clearly been emitted by a luminous gas. With an excess of caution, at the moment I did not venture to go further than to point out that we had here to do with bodies of an order quite different from that of the stars. Further observations soon convinced me that, though the short span of human life is far too minute relatively to cosmical events for us to expect to see in succession any distinct step in so august a process, the probability is, indeed, overwhelming in favor of an evolution in the past, and still going on, of the heavenly hosts. A time surely existed when the matter now condensed into the sun and planets filled the whole space occupied by the solar system, in the condition of gas, which then appeared as a glowing nebula, after the order, it may be, of some now existing in the heavens. There remained no room for doubt that the nebulæ, which our telescopes revealed to us, are the early stages of long processions of cosmical events, which correspond broadly to those required by the nebular hypothesis in one or other of its forms.

Further observations identified two of the lines as due to hydrogen. Observations by various spectroscopists have increased the number of bright lines known to exist in nebular spectra to 30 or 40, but aside from hydrogen and helium, accounting for about one-half of all the observed lines, the chemical constitution of the so-called gaseous nebulæ is unknown.

To leave the subject of the nebular spectrum here would mislead the inexperienced, and it is necessary to say that only a minority of the nebulæ thus far observed in this way show spectra consisting chiefly of bright lines. The spiral nebulæ have spectra chiefly continuous, and their composition and physical state remain a mystery. Even so for bright-line nebulæ, as observed by Huggins in 1864, we cannot say that they are shining by virtue of the heat of incandescence; the tendency of present-day opinion is that their substances are comparatively cool, and that their luminosity must arise from other conditions not now understood with certainty.

Important contributions to our knowledge of temporary stars—the so-called new stars—were made by Huggins in half a dozen papers on their spectra. The principal stars studied were those which ap-

peared suddenly in Corona Borealis, in the Great Nebula in Andromeda, and in Auriga.

Huggins was among the first to apply the spectroscope to the study of comets. A dozen papers by him, on cometary spectra, make interesting reading, for they record the gradual evolution of our knowledge of physical conditions existing in comets up to the year 1882. For example, speaking of observations of Winnecke's comet of 1868 made on the evening of June 22, he says:

When a spectroscope furnished with two prisms of 60° was applied to the telescope, the light of the comet was resolved into three very broad, bright bands. * * *

In the two more refrangible of these bands the light was brightest at the less refrangible end, and gradually diminished toward the other limit of the bands. This gradation of light was not uniform in the middle and brightest band, which continued of nearly equal brilliancy for about one-third of its breadth from the less refrangible end. This band appeared to be commenced at its brightest side by a bright line.

The least refrangible of the three bands did not exhibit a similar marked gradation of brightness. This band, though of nearly uniform brilliancy throughout, was perhaps brightest about the middle of its breadth. * * *

The following day I carefully considered these observations of the comet with the hope of a possible identification of its spectrum with that of some terrestrial substance. The spectrum of the comet appeared to me to resemble some of the forms of the spectrum of carbon which I had observed and carefully measured in 1864. On comparing the spectrum of the comet with the diagrams of these spectra of carbon, I was much interested to preceive that the positions of the bands in the spectrum, as well as their general characters and relative brightness, agreed exactly with the spectrum of carbon when the spark is taken in olefiant gas. * * *

It was with the spectrum of carbon, as thus obtained, that the spectrum of the comet appeared to agree. It seemed, therefore, to be of much importance that the spectrum of the spark in olefiant gas should be compared directly in the spectroscope with the spectrum of the comet. The comparison of the gas with the comet was made the same evening, June 23. * * *

The brightest end of the middle band of the cometic spectrum was seen to be coincident with the commencement of the corresponding band in the spectrum of the spark. As this limit of the band was well defined in both spectra, the coincidence could be satisfactorily observed up to the power of the spectroscope; and may be considered to be determined within about the distance which separates the components of the double line D. As the limits of the other bands were less distinctly seen, the same amount of certainty of exact coincidence could not be obtained. We considered these bands to agree precisely in position with the bands corresponding to them in the spectrum of the spark.

The apparent identity of the spectrum of the comet with that of carbon rests not only on the coincidence of position in the spectrum of the bands, but also upon the very remarkable resemblance of the corresponding bands in their general characters and in their relative brightness. This is very noticeable in the middle band, where the gradation of brightness is not uniform. This band in both spectra remained of nearly equal brightness for the same proportion of its length.

On a subsequent evening, June 25, I repeated these comparisons, when the former observations were fully confirmed in every particular. On this evening I compared the brightest band with that of carbon in the larger spectroscope, which gives a dispersion of about five prisms.

The remarkably close resemblance of the spectrum of the comet to the spectrum of carbon necessarily suggests the identity of the substances by which in both cases the light was emitted.

The application of the Doppler-Fizeau principle to the measurement of stellar velocities has assumed great importance in astronomical investigation. It is now easy to look backward and say that this importance was inevitable, but it was not easy, half a century ago, to look forward and say that this must be so. It is characteristic of the pioneers in this field that they were slow to publish their ideas and observations.

It was Fizeau, in 1848, who first enunciated the principle correctly that motions of approach and recession must cause corresponding shiftings of the entire spectrum, including the dark lines of Fraunhofer, toward the violet and red, respectively, but without change of color. Fizeau also outlined methods for applying the principle to measuring the motions of celestial bodies toward and away from the observer. While these methods were sound theoretically, they were unpractical. All matters spectroscopic were then mysterious, and Fizeau's statements attracted no serious attention. In fact, his lecture on the subject in 1848, before a minor society in Paris, was not published until 1869. In the meantime the subject was receiving attention on the theoretical and laboratory sides from Fizeau and Clerk Maxwell, and on the stellar side from Huggins and Miller, and from Secchi. Secchi's paper in Comptes Rendus, Paris Academy, dated March 2, 1868, describes his search for high velocities of the stars in the line of sight, conducted under encouragement from Fizeau, which led to merely negative conclusions; and he remarked that success in detecting velocities in the line of sight no greater than that of the earth in its orbit would require instrumental equipment more powerful than was then at his disposal.

Almost simultaneously appeared a paper by Huggins and Miller in the Philosophical Transactions, dated April 23, 1868, from which the following paragraph is quoted:

In a paper "On the spectra of some of the fixed stars" by myself and Dr. W. A. Miller, treasurer Royal Society, we gave an account of the method by which we had succeeded during the years 1862 and 1863 in making trustworthy simultaneous comparisons of the bright lines of terrestrial substances with the dark lines in the spectra of some of the fixed stars. We were at the time fully aware that these direct comparisons were not only of value for the more immediate purpose for which they had been undertaken, namely, to obtain information of the chemical constitution of the investing atmospheres of the stars, but that they might also possibly serve to tell us something of the motions

of the stars relatively to our system. If the stars were moving toward or from the earth, their motion, compounded with the earth's motion, would alter to an observer on the earth the refrangibility of the light emitted by them, and consequently the lines of terrestrial substances would no longer coincide in position in the spectrum with the dark lines produced by the absorption of the vapors of the same substances existing in the stars.

Repeated efforts to measure the velocities of recession and approach of the stars were made in later years by Huggins and other observers; and while their results were inaccurate and erroneous, they did not work entirely in vain, for the successes of the later observers in any subject are built, to some extent, upon the failures of the pioneers. We now know that visual methods could not have had more than very moderate success, even under the most favorable conditions. The coming of very sensitive dry-plates has made it possible for a 6-inch telescope and spectrograph to measure the velocities of a greater number of stars than could be done with the 36-inch telescope, using visual methods of spectroscopy.

Perhaps Huggins's greatest contributions to the development of celestial spectroscopy have come from his efforts to interpret the original observations by means of laboratory observations made by himself and others. To these problems he brought philosophic judgment of unusual breadth and depth. His public addresses, reviewing astronomical progress and forecasting the problems of the future, were of unusual interest and excellence. The Cardiff address of 1891 was notable in this regard.

The epoch-making work of Huggins brought him early and full recognition from universities and learned societies. His government alone was slow to reward him. He was Rede lecturer in Cambridge University in 1869; he received the degree of LL. D. from Cambridge in 1870, and the degree of D. C. L. from Oxford in 1870. He was made a member of the Royal Society in 1865. He received the Lalande gold medal and the Janssen gold medal of the Paris Academy of Sciences; the gold medal of the Royal Astronomical Society; the Royal, the Rumford, and the Copley medals of the Royal Society; the Bruce medal of the Astronomical Society of the Pacific; and perhaps others.

He received honorary degrees from many universities, and was elected to membership in the leading academies. He was president of the British Association in 1891, the year of the Cardiff meetings. He was president of the Royal Society during the years 1900–1905. On the occasion of the Diamond Jubilee of Queen Victoria, in his seventy-fourth year, he was knighted; and in his seventy-eighth year he received appointment to the Order of Merit.

It is a law of nature that ripeness must give way to youth. Fortunately, the example and work of such as Huggins live on into

succeeding generations, and the history of astronomy will keep his name on the list of great pioneers.

For 35 years he experienced able and devoted support in his scientific duties and undertakings from Lady Huggins, whose assistance was always real and active. The history of science does not tell us of more devoted coworkers than Sir William and Lady Huggins. The sympathies of all who have had the good fortune to know them go to her who has been left behind.

THE SOLAR CONSTANT OF RADIATION.[1]

By C. G. Abbot,

Director of the Astrophysical Observatory of the Smithsonian Institution.

Langley once wrote:

If the observation of the amount of heat the sun sends the earth is among the most important and difficult in astronomical physics, it may also be termed the fundamental problem of meteorology, nearly all whose phenomena would become predictable if we knew both the original quantity and kind of this heat; how it affects the constituents of the atmosphere on its passage earthward; how much of it reaches the soil; how, through the aid of the atmosphere, it maintains the surface temperature of this planet; and how, in diminished quantity and altered kind, it is finally returned to outer space.

The first great advance in the study of this matter was made by Pouillet more than 70 years ago. He constructed an instrument which he called a "Pyrheliometer." It comprised a shallow circular metallic box blackened to absorb sun rays, having a thermometer inserted in the center of one circular face, and being arranged so as to expose the other circular face broadside toward the sun. The instrument was first shaded for a time, as, for instance, five minutes, then exposed to the sun an equal time, then shaded again. By reading the thermometer before and after each of the intervals just mentioned, the rise of temperature due to the sun, exclusive of the losses and gains of heat due to the surroundings, was thought to be determined. Knowing the water equivalent of the pyrheliometer and the area exposed to the sun, the result could be converted to calories per square centimeter per minute.

But it is not sufficient to know the amount of heat available in the solar beam at the earth's surface, for this is reduced by the amount of haze, dust, and water vapor in the earth's atmosphere, and even, as Rayleigh afterwards showed, diminished by the diffuse reflection of the molecules of air themselves. Hence the intensity of the solar beam not only differs from day to day, but increases between sunrise and noon, and decreases between noon and sunset, depending on the length of path of the beam in the atmosphere. Bouguer and Lambert, independently, about 1760, had derived an exponential formula connecting the intensities of the entering and outgoing beams with

[1] Address by C. G. Abbot to the Solar Union Conference at the Mount Wilson Solar Observatory, California, Wednesday evening, Aug. 31, 1910.

the thickness of the medium traversed. This formula is variously given, but may be used in this form: $E=E_0 A^m$, where E and E_0 are the intensities of the outgoing and entering beams, A a constant expressing the fraction transmitted through unit thickness, and m the thickness traversed. In the case of the atmosphere it is natural to take unit thickness as that of the layer between the observer and the zenith, and m as equal to the secant of the zenith distance of the celestial object. This latter assumption is not strictly true, because the air layer is not a plane parallel sheet, but spherical in curvature, and secondly because the beam is curved by atmospheric refraction. However, as the air layer of sensible density is thin compared with the length of the earth's radius, and as the refraction is negligible except near the horizon, the approximation is very close for zenith distances less than 75°, for which $m=4$. Knowing m and measuring E by the pyrheliometer, two observations at different zenith distances fix the values of E_0 and A. Pouillet, proceeding in some such manner, made numerous determinations of these quantities, and concluded that the value of E_0 at mean solar distance is about 1.76 calories per square centimeter per minute. This, then, is Pouillet's value of the "solar constant of radiation."

For the next 40 years this result was generally adopted, although the experiments of Forbes, Violle, and Crova and the theoretical work of Radau indicated that it was too low. Langley, about 1880, stated Radau's argument in a highly convincing form. Briefly stated, since the transmission of the atmosphere differs, depending on whether we consider blue or red light, and especially on whether we treat of rays which suffer only the general scattering of the molecules and dust particles of the air, or take those which are selectively absorbed by water vapor and oxygen, and which are almost completely extinguished high above the earth's surface—on account of this inequality of atmospheric extinction Pouillet's method inevitably yields too low results.

Langley, by the aid of his then newly invented bolometer, measured at Allegheny, and in 1881 at Lone Pine and Mount Whitney, the transmission of the spectral rays separately, computed how the energy of the sun is distributed in its spectrum outside the atmosphere, and fixed a new value of the solar constant which has been generally accepted almost until the present time.

The method of Langley, which is that now in use, is complex, but necessarily so. Imagine that you have a very intense solar spectrum before you, and that it is still early morning, with the sun perhaps an hour and a half high. If you had a thin, delicate, blackened thermometer you could carry it along in the spectrum from the extreme ultra-violet to far beyond the red end of the visible spectrum, and detect varying degrees of temperature rise proportional to the

heat produced by each spectral ray. At each of the Fraunhofer lines the thermometer would fall slightly. The great A band of oxygen would produce a large decrease of temperature, but beyond the red you would think several times you had reached the end of the spectrum if you did not know better, and that you were examining great water-vapor bands. Suppose now that several hours later you repeated the experiment. You would find that, excepting in these great water-vapor bands, practically every part of the spectrum was hotter than before, and that the change had been greatest in the violet end. At any selected wave length you could then apply the method of Pouillet, and find what your instrument would have indicated if you could have read its rise of temperature due to the heat of the solar spectral ray outside of the air altogether.

It would be natural to plot upon a convenient scale the spectral distribution at the earth's surface, and outside the atmosphere, using intensities of the spectrum as ordinates, and wave lengths, or prismatic deviations, as abscissae. The total area included between such a curve and the axis of abscissae (or zero intensity) is proportional to the total radiation of all colors combined. Hence the ratio between the computed area outside the atmosphere and that measured at the earth's surface is the ratio which would be found between the readings of the pyrheliometer if one could read it outside the atmosphere and again at the given hour at the earth's surface. So we should determine the "solar constant" by multiplying the pyrheliometer reading at the earth's surface for the given hour by the ratio just mentioned, and then reducing the result to mean solar distance. One thing, however, is to be considered. The energy in the great atmospheric absorption bands of the infra-red spectrum does not increase fast enough, as the path of the beam diminishes, to fully obliterate the bands in the energy curve computed for outside the atmosphere. But we know that there is no absorption in these bands due to the sun itself. They are solely atmospheric. Hence in drawing our extra-atmospheric computed curve we draw it smoothly so as to eliminate all atmospheric bands. The remaining solar Fraunhofer lines may be blurred over by using a wide slit of the spectroscope, or, better still, a smooth energy curve representing average intensities may be drawn to allow for them, both within and without the atmosphere. As for the ultra-violet and infra-red regions beyond what is convenient to observe, corrections of a few per cent are added for them.

Such, in brief, is the method of Langley for determining the solar constant of radiation. Unfortunately in this pioneering work he came to distrust the application of the exponential formula of Bouguer to the atmosphere, even when applied as he did it to homo-

geneous, that is to say, monochromatic rays. He was thus led to fix the solar constant at 3 calories per square centimeter per minute, which now appears to be fully three halves the true value. I quote his own words in description of the method by which this value was derived:

> We now proceed to determine from our bolometer observations a value which we may believe * * * to be a *minimum* of the "solar constant," and one within the probable truth. All the evidence we possess shows * * * that the atmosphere grows more transmissible as we ascend, or that for equal weights of air the transmissibility increases (and probably continuously) as we go up higher. In finding our minimum value we proceed as follows, still dealing with rays which are as approximately homogeneous as we can experimentally obtain them. Let us take one of these rays as an example, and let it be the one whose wave length is 0.6μ, and which caused a deflection at Lone Pine of 201. The coefficient of transmission of this ray, as determined by high and low sun at Lone Pine and referred to the vertical air mass between Lone Pine and Mountain Camp, is 0.976. From the observations at Lone Pine, then, the heat of this ray upon the mountain should have been
>
> $$201 \times \frac{1000}{976} = 206.0,$$
>
> but the heat in this ray actually observed on the mountain was 249.7. Therefore, multiplying the value for the energy of this ray outside the atmosphere calculated from Mountain Camp high and low sun observations (275) by the ratio $\frac{2497}{2060}$, we have 333.3, where 333.3 represents the energy in this ray outside the atmosphere as determined by this second process.

By this process Langley obtained the solar-constant value 2.630 calories, which he considered a minimum. By another process he obtained the value 3.505, which he considered a maximum. The mean of the two he chose as the solar constant, or, in round numbers, 3 calories.

Langley's argument is, of course, that if we find our formula giving too small values at a station within the atmosphere to which we can ascend, probably it would give values even smaller in proportion to the true one outside the atmosphere altogether where we can not go to test it. But in fact the transmission coefficient found at Lone Pine was not applicable to compute what ought to have been observed at Mountain Camp. It was applicable to the average transmissibility of all the layers of the air from Lone Pine to the limit of the atmosphere. It was therefore *far too high* to suit the transmission of the dusty, opaque layers next the earth's surface. Hence, by its use Langley computed a smaller value for Mountain Camp than he observed, but this had really no bearing on the problem. It would seem that the true result to be selected as representing Langley's experiments is the mean of 2.06 found by the unmodified method of homogeneous rays at Lone Pine and 2.22 found in the same way at Mountain Camp. That mean is 2.14 calories.

After Langley, everybody admitted that "solar constant" work required observation of homogenous rays, but nobody practiced it until 1902, when such observations were begun in Washington at the Smithsonian Astrophysical Observatory. In the meantime important advances had come. The brilliant work in Germany from 1890 to 1900 had fixed the laws and constants of radiation for the perfect radiator or "absolutely black body" of Kirchhoff. Hence we knew approximately that the sun was of the order of 6,000° in absolute temperature (centigrade), and that as its spectrum energy curve determined by Langley was generally similar to that of a "black body," there could be no very appreciable fraction of its radiation beyond 3μ in the infra-red, or beyond 0.3μ in the ultra-violet. The positions of the infra-red atmospheric absorption bands had been determined, and they had been assigned to water vapor and carbon dioxide. The bands of the latter compound had been found to lie beyond the spectral region just named, and hence to be of little account to diminish solar radiation, so that Ångström, in 1901, withdrew his solar-constant value 4 calories, which he had based on a supposed enormous carbon-dioxide absorption.

Great improvement had been made in the bolometer. For "solar constant" work this instrument comprises essentially two little threads or tapes of platinum, each about 1 centimeter long, 0.01 centimeter wide, and 0.001 centimeter thick. They are blackened to absorb rays, but one is hidden from the spectrum while the other is exposed to it, so that the latter is warmed by the rays with respect to the former. Two equal resistance coils are joined to the two bolometer tapes, so that the whole forms a "Wheatstone's bridge." The rise of temperature of one of the tapes increases its electrical resistance, and causes a very minute electrical current to flow and deflect a highly sensitive galvanometer. In ordinary bolometric practice a rise of temperature $\frac{1}{100000}$° centigrade is readily observed.

You will not wonder that when this instrument was a new one it was almost unmanageable. Langley has told me often that in the hot tent at Lone Pine the galvanometer light spot used to rush off the scale, 1 meter long, in a single minute. Hence it took several men to make an observation. One sat, sweltering (this was the immortal Keeler), reading the scale as fast as he could, while another recorded his numbers and also set the spectroscope. One let the sun on and off the spectroscope and kept the irregularly running siderostat reflecting the beam approximately right. A fourth observed with the Violle pyrheliometer. It took thousands and thousands of observations to determine a "solar constant" under such circumstances. The deflections could be worked out only by plotting the almost innumerable galvanometer readings which the observer had made without

knowing if the sun was on or off. It is wonderful that out of such a maze the truth was approximately found at last.

When the Astrophysical Observatory was founded at Washington the bolometer had been so far subdued that Langley introduced the beautiful device of photographically recording the galvanometer light spot on a moving plate, while the same clock which moved the plate also moved the spectrum over the bolometer tape. Thus an automatic solar spectrum energy curve could be taken without making a single galvanometer reading. But "drift," though no longer a meter a minute, was still an obstacle. Several devices have since been applied by means of which "drift" is practically eliminated, so that the galvanometer light spot stays day after day practically unmoved, except as the sun is allowed to shine through the spectroscope. We now usually take an energy curve of the solar spectrum, running from the band of silver transmission near wave length 0.33μ in the ultra-violet, to wave length 2.5μ in the infra-red in eight minutes. Such a curve shows more than even Keeler could have found with the old apparatus in a lifetime. One observer may now easily carry on "solar constant" work without help.

In his "Report of the Mount Whitney Expedition," Langley states that the measurement of the "solar constant" encounters two difficulties, one of which he describes as "formidable," the other as "perhaps insurmountable." The first is the difficulty of completely absorbing and accurately measuring the intensity of the solar rays as they reach the earth's surface. The second is the difficulty of correctly estimating the loss they suffer in traversing the atmosphere. We shall recur to the latter. After eight years of effort to overcome the former I agree that it was "formidable."

In 1894 Prof. V. A. Michelson, of Russia, published an account of his pyrheliometer. In this instrument he employed a tube-like chamber, blackened within to absorb the rays, and surrounded by melting ice and water. The amount of solar heating he determined by noting the increase of volume of the ice as it melted, reading for this purpose a graduated capillary tube attached to the outer chamber wall. Michelson's pyrheliometer, which has been, I think, little used, may have given correct results, but excepting for it I believe there has been no accurate standard pyrheliometry until this year, 1910. Unfortunately the importance of Michelson's device was overlooked because his description was published in the Russian language.

The electrical compensation pyrheliometer of Ångström was described in 1898, and has attained wide acceptance. It was adopted by the Solar Union as a standard at the Oxford Conference, but the experience of Kimball and of Callendar is unfavorable to it, for there is a deterioration after some years in practically every in-

strument. Besides this, there is reason to believe that the instrument reads too low, even at the first.

In most pyrheliometers, as in that of Pouillet, there is a blackened exterior surface for the reception of the solar radiation, behind which lies a device for measuring temperature. There are two possible paths for the heat produced, one by conduction back to the temperature device, one by convection and radiation forward into the air. This second part of the heat is lost, and is undetermined, though not large in amount. Besides this loss is a second by direct reflection of rays from the surface. This second loss is usually allowed for, but its determination is not easy. Both these sources of error are avoided in the hollow chamber instrument of Michelson.

When in 1902 we began at Washington the study of the "solar constant" we fortunately, though quite innocently, did not employ Ångström's pyrheliometer. We had received from the late M. Crova two of his alcohol actinometers, and of these he said in a letter, with delightful naïveté, that they were good secondary instruments and only required to be calibrated by comparison with *any satisfactory standard.* At that time there was no standard. So we cast about for one, and, following Tyndall, who had followed Pouillet, I had our instrument maker, Mr. Kramer, prepare a shallow, circular copper box with a thermometer inserted at the side, and with mercury filling the box to the blackened cover. The whole was surrounded by a wooden chamber to keep off the wind. By calorimetric measurements we attempted to get the water equivalent of this mercury pyrheliometer, and our subsequent measurements were all given, for years, in terms of the scale it furnished. We soon found our mercury pyrheliometer more convenient than the Crova actinometer, and abandoned the use of the latter. Afterwards we recognized that, on account of the great variation of the specific heat of alcohol with change of temperature, we should have been all at sea if we had continued to use Crova's instrument. Later we dispensed almost wholly with the mercury and used a solid, circular, thin copper block, with a radial hole for inserting the cylindrical bulb thermometer, using only enough mercury to make good heat conduction to the thermometer. Finally we have bent the stem of the thermometer at right angles, employed a steel-lined silver block, have equipped the instrument with various effective little auxiliary devices, and by the aid of a grant from the Hodgkins fund by the Secretary of the Smithsonian Institution, have sent several of our silver-disk pyrheliometers to Europe, to promote international agreement in pyrheliometry.

But although our scale of pyrheliometry was fortified by comparison of numerous copper and silver disk instruments among them-

selves, and though we found by these intercomparisons that the scale remained unchanged from year to year, we yet felt sure that it was not the standard scale of calories. In 1903, not knowing of Michelson's idea of a decade earlier, I conceived the idea of employing the hollow chamber, or "absolutely black-body" principle. Instead of combining with it the Bunsen ice-calorimeter method I proposed to make the walls of the chamber hollow and to circulate a measured current of water through them, which should carry off the heat as fast as formed. The rise of temperature of this water I proposed to measure by a platinum-resistance thermometer immersed half in the incoming, half in the outflowing water. To test the accuracy of the results I proposed to insert a coil of resistance wire within the chamber and to measure a known quantity of electrical heating which could be introduced thereby in terms of the rise of temperature it produced in the water. This program, after seven years, and the successive building of three, all supposedly final, water-flow pyrheliometers is now satisfactorily completed. I can not praise too highly Mr. Kramer's admirable skill in the construction of these instruments. A careful comparison, completed by Mr. Aldrich this spring in Washington, of standard pyrheliometers No. 2 and No. 3 with secondary pyrheliometer No. 8, and through this with secondary No. 4, used since 1906, on Mount Wilson, has resulted as follows:

Constant of secondary pyrheliometer No. 4.

By standard No. 2	0.8553
By standard No. 3	0.8550

In these comparisons electrical heating was frequently introduced as a check, and the heat found seldom deviated more than 1 per cent from 100 per cent of that introduced. On the average about 99.5 per cent was found.

I consider that now the obstacle to solar-constant work called "formidable" by Langley is overcome, and that we may know the amount of solar heat received at the earth's surface within a quarter of 1 per cent.

It is not probable that I should have been here this evening if it had not happened that our "solar constant" values of 1903 indicated a fall of solar radiation of about 10 per cent at a time just before there occurred a general fall of several degrees centigrade from the normal temperature of the United States and Europe. This led to the suspicion that the "solar constant" was a misnomer, and that the sun's emission is really variable. After further studies in Washington, hindered by long periods of cloudiness, I was sent by Mr. Langley in 1905, at Prof. Hale's invitation, to occupy for the summer a temporary station here on Mount Wilson. As I was about to start Mr. Langley directed me to remember that I was going not to fix the

average value of the "solar constant," but to observe its possible variability. "In fact," said he, with a twinkle in his eye, "I may tell you that I consider that value of the solar constant as best which nearest approaches 3 calories." You will perhaps infer from this that I had expressed to him the views regarding his Mount Whitney result which I have given here this evening. He replied that the Mount Whitney work was done in the prime of his life, and now that he was old and had laid the subject aside for so long he did not feel that he could reason upon it as acutely as he could have done at that time, and therefore he would let his former value stand.

In 1905, 1906, 1908, 1909, and now in 1910 I shall have occupied for six months each year the Mount Wilson Smithsonian station, which has now become the permanent cement structure which many of you have visited. It is a pleasure to acknowledge the aid, inspiration, and friendly companionship which I have had from Mr. Hale and his staff. In this interval, partly with the aid of Messrs. Ingersoll and Aldrich in different seasons, but much of the time alone (so much are instrumental conditions superior now to those of Langley's early work), I have made series of spectro-bolometric and pyrheliometric observations for the determination of the "solar constant" on about 400 different days. During 1905 and 1906 Mr. Fowle was carrying or nearly simultaneous, similar observations in Washington whenever conditions permitted. Although the direct readings at the two stations differed by about 20 per cent on account of the relative conditions at sea level and 1,800 meters elevation, yet our "solar constant" results agreed within the experimental error at Washington; that is, within 3 per cent on the average.

In 1908 I went to the summit of Mount Whitney with Prof. Campbell, and we united to recommend the erection there of a permanent shelter by the Smithsonian Institution. This was approved by Secretary Walcott, and a three-room stone and steel house was built in August, 1909, by aid of a Hodgkins grant, and is now available to all students of science who shall receive permission of the secretary to use it. In 1909 I returned to Mount Whitney with a spectro-bolometric outfit, and made a complete determination of the "solar constant" on September 3, simultaneously with a complete determination by Mr. Ingersoll here on Mount Wilson. My result differed from his by less than 1 per cent, although my direct readings were, of course, fully 15 per cent higher than his, on account of the higher elevation of Mount Whitney, 4,420 meters.

I have just returned from a third trip to Mount Whitney, on which I had, fortunately, excellent weather during all the time when I desired it. During my stay I made complete "solar constant" observations on four days simultaneous with those of Mr. Fowle here on Mount Wilson; I observed with Prof. Kapteyn's photometer on two

nights; made bolometric measurements of the water-vapor bands in the infra-red spectrum on one day; and measured with the bolometer on two days the relative brightness of the sun and many different parts of the sky. My expedition lacked the picturesqueness and éclat which distinguished Langley's, with its private car, its guard of cavalry, and a budding astronomer of the first rank, the renowned Keeler, as assistant. However, I rode from Mojave to Lone Pine (about 150 miles) in an automobile trying all the while desperately to keep my pyrheliometer from being broken, and was consequently jounced myself, once to the roof of the automobile, and barely escaped a broken nose. My treasured pyrheliometer afterwards rolled down the Mount Whitney trail twice with the pack mule, and the second time the mule was killed, but the instrument reached the top in safety. My measurements of 1910 are, of course, not yet reduced.

Considering that practically identical results have been obtained by simultaneous "solar constant" measurements at sea level (Washington) and 1,800 meters (Mount Wilson), and again at 1,800 meters and 4,420 meters (Mount Whitney), observing by the spectro-bolometric method of homogeneous rays in each case, I think we must admit that Langley's second difficulty was a bugbear and not an insuperable obstacle. I therefore venture to announce that I believe the true average value of the "solar constant" of radiation is for the years 1905 to 1909, 1.92 calories per square centimeter per minute. We know that the earth's temperature is higher at sun-spot minimum that at maximum. Hence I suppose that the values so far observed are a little below the mean for a term of years, and I propose as the most probable mean value of the "solar constant" 1.95 calories per square centimeter per minute.

Our results at Mount Wilson have strongly confirmed the impression gained in 1903 that the "solar constant" is really a variable of short and irregular periodicity. We have tested this conclusion by all means in our power. But the one obvious and necessary test, that of establishing a second far-distant cloudless station and carrying on there with equal facilities and experience a series of "solar constant" measurements simultaneous with those on Mount Wilson, we have not been able to make for lack of funds.

ASTRONOMICAL PROBLEMS OF THE SOUTHERN HEMISPHERE.[1]

By Heber D. Curtis.

It is a natural result of the more recent development of the civilizations of the Southern Hemisphere that advances in the science of astronomy should likewise be less extensive than those made by the parent civilizations of the Northern Hemisphere. From the nature of the case, the Southern Hemisphere possesses relatively few astronomical records which can compare, in point of time, with those obtained for the northern skies during the last two centuries; and in the past, but to a less extent to-day, no small part of the progress made in mapping and studying the southern skies has been made by expeditions from the older foundations of Europe and America.

Probably the first observatory south of the equator which can be described as of a permanent character was that founded by Sir Thomas Brisbane in Paramatta, New South Wales, as a private observatory, in 1821; its period of activity extended over about 10 years, and it was later incorporated with the Observatory of Sydney. An observatory was founded in Buenos Aires in 1822, but its period of activity was very short. Although the Observatory of the Cape of Good Hope was founded in 1820, its activity did not commence till 1829, the date of its completion; the extremely valuable and extensive work carried on here during the 80 years past give to it the unchallenged rank as the oldest permanent astronomical foundation in the Southern Hemisphere. At a later date we find the foundation of the Observatory of Santiago in 1856; Melbourne, founded in Williamstown, Victoria, in 1853, and transferred to Melbourne in 1861; Adelaide, established in 1854; Córdoba, 1870; Arequipa in 1891, and others of more recent date. Among the early expeditions of a temporary character may be noted the visit of Halley to St. Helena in 1677; later we come to the appearance of the first large systematic catalogue of the southern stars by Lacaille as a

[1] Reprinted by permission, with author's revision from publications of the Astronomical Society of the Pacific, vol. 21, No. 129, San Francisco, Cal., Dec. 10, 1909.

result of his stay of four years at the Cape of Good Hope in the years 1751–1755; the noteworthy investigations made at the same spot by Sir John Herschel, from 1834 to 1838; the expedition sent to Santiago under charge of Gilliss in 1849; and others of more recent date to which attention will be called later.

The observatories in the southern part of the north temperate zone can extend their investigations in many lines of astronomical research to a distance of 30° to the south of the celestial equator without great difficulty or loss of accuracy, but from this limit to the South Pole we have a region amounting to about one-fourth of the entire sky which, relatively to the northern skies, was almost as much a terra incognita 75 years ago as was Central Africa at the same date, and which to-day contains many virgin fields which offer rich returns to the exploring astronomer.

In the first great subdivision of astronomy, the astronomy of position, whose field is primarily the determination of the accurate positions of the fixed stars, the observed changes in these positions are so minute that the element of time becomes the most important factor to enable conclusions to be drawn from a given mass of observations as to the proper motions of the stars and the structure of the sidereal universe as a whole. Because of this relatively short time factor since the earlier exact observations of the positions of the southern stars, the astronomy of precision of the Southern Hemisphere can not yet compete with the results from the northern heavens. Sir David Gill has said, and there is doubtless no more competent authority to pronounce upon this point than he, that the state of our knowledge of the exact positions of the stars of the Southern Hemisphere is at least a century behind that of the Northern Hemisphere. Nevertheless, if we consider the results already secured in the exact cartography of the southern skies, and take into consideration also the researches in this field at present well under way, we may safely reach the conclusion that the coming 20 years will render our knowledge of southern star positions very little inferior to those of the northern skies, always excepting, in this conclusion, the disadvantage arising from the lack of early observations, a lack which will necessitate the accumulation of results for many years before our knowledge of southern proper motions can equal that of the northern stars.

In this task of bettering our knowledge of exact star positions in the Southern Hemisphere it is doubtless superfluous to mention here the excellent work that has been done in the past and is now in progress at a number of southern observatories, especially the extensive results from Córdoba and the Cape of Good Hope. In 1865 the Astronomische Gesellschaft undertook the extensive task of mapping, by means of exact meridian observations, all the stars in the sky down to the ninth magnitude. This work for the Northern Hemi-

sphere and for some distance south of the celestial equator is now practically completed, and the work is advancing favorably for the more southerly portions of the sky at the observatories of Madras, Melbourne, and the Cape.

One of the most important programs in connection with the astronomy of precision of the Southern Hemisphere is that inaugurated in 1908 under the auspieces of the Carnegie Institution of Washington. It has for its object the measurement of the accurate positions of about 25,000 stars in the southern skies in accordance with the system of Prof. Boss, of Dudley Observatory. The instrument employed is the meridian circle of the Dudley Observatory, which has been used in the past for exactly similar work in the northern skies. The constants, graduation errors, etc., of this instrument have been so thoroughly investigated that doubtless no more efficient instrument exists to-day for this class of work. By the use of the same instrument, the same system of reductions, and to a certain extent even the same observers, it seems probable that the results of this program will afford us a far more exact binding together of the northern and southern skies in one homogeneous system than we possess to-day. The site was selected at San Luis, in the Argentine Republic. Prof. Tucker, of the Lick Observatory, was in charge of the Carnegie Observatory at San Luis and advices state that the site seems to be a very favorable one for this class of work. The program has been completed as planned and the observers are now (April, 1911) returning to the United States, where the results will be put in final shape for publication. The project involved about 3 years' work, and about seven observers and assistants were employed.

In the years 1885–1891, under the direction of Sir David Gill, the Observatory of the Cape of Good Hope undertook an extensive photographic map of the southern skies from declination —19° to the South Pole. The measurement of the positions of the stars on these plates was carried through by the disinterested and self-sacrificing labors of Prof. Kapteyn, and the publication in 1900 of the third and concluding volume of the great "Cape Photographic Durchmusterung" marked the completion of this monumental task. It contains the positions of 454,875 stars, nearly to the tenth magnitude, and the positions are accurate to about 1 second of arc. It is an epoch-making work in the cartography of the southern heavens; in fact, until the completion of the "Astrographic Catalogue" no such complete and systematic photographic catalogue exists for the Northern Hemisphere. Naturally it can not compete, however, with the accuracy of the "Astrographic Charts"; those from Helsingfors, for example, having the small probable error of 0.11″ for the mean of two measured star images.

Without doubt, however, the greatest problem in the cartography of the southern skies which awaits the observatories of the Southern Hemisphere is the completion of their respective shares in the great photographic map of the heavens mentioned above, which was inaugurated at the International Conference in Paris in 1887. As is well known, this plan, in its entirety, involved the construction of a photographic map of the entire sky down to the fourteenth stellar magnitude, for which about 22,000 plates were to be taken, and the total number of the stars registered on the plates would probably reach 20,000,000. Supplementary to these charts the plans contemplated the publication of a great catalogue of perhaps 2,000,000 stars down to the eleventh magnitude, based on plates or shorter exposure time. The task was apportioned among 18 observatories in the two hemispheres. The observatories south of the Equator which possess photographic equatorials of the uniform type adopted for the work are those at La Plata, Córdoba, the Cape, Santiago, Perth, Melbourne, and Sydney. It was proposed that the entire work be repeated in 100 years. But so vast is the scope of this program that even in the Northern Hemisphere this project, whose value for the astronomy of position of the future can scarcely be overestimated, has by no means made the progress anticipated for it at the time of its inception. Owing to the cost, only a few of the cooperating observatories have agreed to publish the great maps, and among southern observatories Perth has decided to take only the plates to the eleventh magnitude and to publish the resulting catalogue. Perth has taken all the plates in its zone, and has commenced the measures for the Catalogue. The section apportioned to the Cape of Good Hope is now nearly completed, both as to the taking of the plates and their measurement, and rapid progress is being made at Sydney, Melbourne, and Córdoba. Up in 1908 nothing had been done at La Plata or Santiago, though Dr. Ristenpart, recently appointed director of the National Observatory at Santiago, will make every effort for the prompt completion of the zone assigned to him; the work of taking the plates has already been begun under the direction of Dr. Zurhellen. It would seem that the publication of the costly maps might well be abandoned, for the plan adopted at Oxford of publishing only the coordinates of the stars would be far cheaper and fully as useful.

Excellent work has been done in determination of stellar parallax at the Cape of Good Hope, but the difficult field of work which has for its aim the determination of the distances of the stars by the heliometer or modern photographic methods is still practically untouched in the Southern Hemisphere. Parallaxes of only 17 stars south of declination —30° have been published, while north of this

limit about 300 parallaxes have been determined, many of them a number of times, by different observers and different methods.

In the interesting field of double stars, as is well known, Herschel discovered many systems in the southern skies, and modern observers, as Innes, Taylor, and others, have materially augumented this number. During the past decade Profs. Aitken and Hussey have been making a very complete and systematic search for such doubles in the Northern Celestial Hemisphere, with the result that several thousand new doubles have been discovered, many of them of great interest. They have reached the conclusion that at least 1 in every 18 stars brighter than the ninth magnitude is a visual binary system. To these results we must add the evidence of the spectroscope that 1 in every 5 or 6 of the stars thus far examined is a spectroscopic double, and we have facts whose importance it is scarcely possible to overestimate in their bearing on our theories of stellar evolution. Such systematic researches for the discovery of visual doubles are most urgently needed in the southern skies to round out the program which these astronomers have now nearly completed for the northern portions of the heavens. In this regard there is no doubt that the southern sky offers one of the richest and most promising fields of research existing to-day. Burnham's great "Catalogue of Double Stars," recently published by the Carnegie Institution, includes 13,665 pairs of stars and extends to south declination 31°. This eminent authoritiy estimates that a century must pass before sufficient data can be collected to make a similar catalogue necessary for the Southern Hemisphere. Innes's "Reference Catalogue of Southern Double Stars"[1] contains 2,191 pairs between the Equator and the South Pole, but of this number about 925 are between the Equator and Burnham's southern limit, nearly all of which have been discovered by observers in the Northern Hemisphere. A comparison of the number remaining, south of —31°, with the results from the northern skies will show clearly that there may well be 2,000 double stars brighter than the ninth magnitude at present awaiting discovery in the Southern Hemisphere, to say nothing of the need for additional researches on the pairs already known.

During the past 10 years systematic observations have been made at six special stations in the Northern Hemisphere to study the small oscillations of the axis of the earth known as the variation of latitude. These stations are located at Mizusawa, Japan; Tschardjui, Asiatic Russia; Carloforte, Italy, and at Gaithersburg, Md.; Cincinnati, Ohio, and Ukiah, Cal.; and are all situated almost exactly on the parallel of north latitude 39° 8′. In 1905 the association which has this research in hand, Das Centralbureau der Internationalen Erdmessung, decided to extend this series of observations to the

[1] Cape Annals, vol. 2, pt. 2, 1899.

Southern Hemisphere, and the plans at first contemplated three stations: in Sydney, Australia; Capetown, Africa; and Santiago, Chile. It was pointed out, however, by Dr. Helmert that better results could be secured, as far as the evaluation of the so-called Kimura-term in the latitude equation was concerned, by two stations placed as exactly as possible on opposite sides of the earth. Accordingly, after correspondence with authorities in Australia and the Argentine Republic, two cites were chosen in 1905 which satisfy this condition, and are, in addition, admirably situated as regards climatic advantages. Both are in south latitude 31° 55′ 15″, and differ 179° 36′ in their longitudes. The Australian installation is in charge of Dr. Hessen, formerly of Berlin, and is located at Bayswater, West Australia, about 4 miles from Perth, the capital. The Argentine station is under the direction of Dr. Luigi Carnera, formerly occupied in similar observations at Carloforte, and is located at Oncativo, about 45 miles from Córdoba.

Both of these stations commenced observations in 1906, and the work has been prosecuted with great energy since that date.[1] The results thus far secured are enabling us to draw more accurate conclusions with regard to these supplementary, exceedingly minute movements of the earth's axis.

The formula for the variation of latitude is ordinarily expressed by the equation

$$\phi - \phi' = x \cos \lambda + y \sin \lambda + z,$$

where x and y are the components of the variation in the planes of zero longitude and that perpendicular to this, while the term z, called the Kimura-term from the Japanese astronomer who suggested its introduction denotes that part of the variation which is common to all the stations, corresponding to an apparent movement of the center of gravity of the earth toward one or the other pole. The results from the northern stations have revealed the interesting fact that the value of z is periodic, with a period of one year, reaching its zero values about March 9 and September 12, and its maximum and minimum values on June 10 and December 10, these points coming, then, about 10 days before the solstitial points. The preliminary results from the southern stations coincide almost exactly with those from the northern stations with respect to the magnitudes of x and y, and show, in addition, that the value of the z-term is of the same magnitude and algebraic sign as that derived from the northern results. This z-term is very small, oscillating only 0.″046 on each side of the mean, which, if real, would correspond to a movement of the center of gravity of the earth of about 4½ feet toward the North or the South Pole. The temptation is very strong to seek a meteoro-

[1] The observations at Bayswater were discontinued in January, 1909; the station at Oncativo has been taken over by the Government of the Argentine Republic.

logical explanation for this small shift of the plane of the Equator. The accumulation of snow and ice at one pole, together with the corresponding diminution at the other pole, due to the melting in the summer season, would be perhaps sufficient to explain the shift, but if this were the true and only explanation, it is difficult to see why the maxima and minima do not follow the solstitial points by a considerable interval of "lag," instead of preceding them by about 10 days.[1] Moreover, the quantities involved are so extremely minute, such transcendental care is necessary in arranging and making the observations, and such pains to exclude in the investigation all possible sources of systematic error, that astronomers are by no means in accord as to the real existence of the z-term. Biske has shown that a variation similar to that afforded by the z-term could arise as a result of inaccuracies in the adopted value of the solar nutation, and that future progressive changes in this value could result from similar slight errors in the adopted value of the lunar nutation. Quite recently Prof. Hiroyama, of Tokio, has subjected the results of the first four years of the latitude variation results to a careful analysis, and reached the conclusion that the z-term is probably a result of errors which may be classified as instrumental. He did not include in his researches, however, the results from the southern stations.

Probably no more marked case of modern specialization in the science of astronomy, no more fitting example of minute and careful analysis, nor any better illustration of the mutual interdependence of fields of investigation apparently widely separated, can be found than this same subject of the variation of latitude. Long since, Euler, from purely mathematical considerations with regard to a rotating spheroid, showed that the axis of the earth should be subject to a minute oscillation, with a period of 305 days. In 1890–91 Prof. Küstner announced that this prediction had been confirmed by observation, but that the period was about 427 days. So minute is the movement that the poles shift from their mean position by less than 30 feet. Eight special observatories have been established, six in the Northern Hemisphere and two in the Southern, and experienced observers are carefully accumulating the observations for the further study of this variation, determining from observations of the stars a periodic movement of the positions of the poles of the earth only a little greater than the distance from one wall of their small observatories to the other, and even showing, with some probability, that the earth's center of gravity oscillates once a year a distance of only a little over 4 feet toward one pole or the other. From these results Darwin, Hough, Larmor, and others have undertaken

[1] Later studies seem to indicate that the maxima and minima in the z-term are slowly shifting.

the investigation of the difference between the observed period of 427 days and that of 305 called for by theory, finding the explanation in the slight yielding of the earth, and have deduced the result that the earth as a whole must possess an effective rigidity a little greater than that of steel. In confirmation of these results, tidal students have found evidences, though very slight, of a minute tide with a period of 430 days. And in still another field these results may possibly prove of interest. No less an authority on earthquakes than Prof. Milne has expressed the opinion that earthquakes are more frequent at those epochs when the axis of the earth is farthest from its mean position, though this theory is not accepted by most seismologists.

In the wide field of stellar photometry a very large proportion of our knowledge of the southern stars comes from the results of the Harvard photometric expeditions and particularly from its station at Arequipa, Peru. Through the visual results secured at Córdoba, the photographic magnitudes as given by the Cape Photographic Durchmusterung and the long series of exact visual estimations made with the meridian photometer at Arequipa, we may say that, except in certain special studies on the fainter stars, the state of our knowledge of the relative brilliancy of the stars of the Southern Hemisphere is not inferior to that of the Northern Hemisphere.

From this station, too, has come far the largest proportion of what is known to-day with reference to the variable stars in the more southerly regions of the sky. Epoch making in this branch is the discovery by Prof. Bailey of a very large number of variable stars in clusters. The Magellanic Clouds and other clusters in the Southern Hemisphere have alone given about 2,000 new variable stars; the determination of the periods of all these and the study of the peculiarities in their variation will in itself furnish work for many years to come. Much remains to be done as well on the brighter variable stars of the Southern Hemisphere.

Through the excellent work at Arequipa, also, Harvard's extensive spectographic surveys have been extended to the South Pole. While it is certain that future studies with spectrographs of higher dispersion will bring forth many new facts with regard to stellar constitution, there is no doubt that Harvard's extensive surveys of the entire sky in the photometric and spectrographic fields will for decades be to the astrophysicist what the Bonn Durchmusterung has been to the worker in the astronomy of position.

As in the surveys just mentioned, the spectrograph was at first employed solely to determine the constituent elements of the sun and the stars, but the application of the Doppler-Fizeau principle to the determination of a star's velocity in the line of sight from its

spectrum has opened up to astronomy a field so vast that we scarcely dare to-day even to demark its boundaries. Few are the fields of astronomical research where the work in radial velocities is not making itself felt, and to-day we are furnished with the interesting spectacle of the oldest astronomy of position and the newer astronomy of the spectrum drawing closer and closer together for the solution of problems of sidereal structure. In order to determine the motion of our sun through space many analyses have been made of the minute proper motions of the stars across our line of vision, but all such determinations are subject to some uncertainty because of the fact that the true distances of the stars whose proper motions are used in the analyses are, in general, very imperfectly known. On the other hand, the spectrograph gives us the velocity of a star in the line of sight, a velocity which, in stars possessing good spectral lines, is accurate within a few tenths of a kilometer per second, and which is entirely independent of the distance of the star from our system. For this reason it should be possible to determine from the radial velocities of a considerable number of stars well distributed over the entire sky a much more accurate value of the amount and the direction of the movement of the solar system through space.

For a complete solution of this problem, at which Dr. Campbell and his associates have been working during the past 15 years, it was necessary that radial velocities be secured for the stars in the Southern Hemisphere. This need was laid before Mr. D. O. Mills, who, in 1902, generously gave the funds necessary for the installation on Mount San Cristóbal, Santiago, Chile, of a 37-inch reflecting telescope with the necessary spectrographic equipment, and in 1905 advanced further funds to continue the southern work for five years longer. A further extension of the work for two years has been made possible through funds supplied by Mr. Ogden Mills, son of the late D. O. Mills.

Up to date about 7,200 spectrograms have been taken at Mount Hamilton and 3,700 by the D. O. Mills expedition at Santiago, on nearly 1,400 stars. The northern portion of the program is nearly completed, and two years more should see the southern portions of the work essentially finished, though decades could well be used in investigating the "by-products" which have appeared in the course of the work, and other decades for the much-needed extension of these researches to fainter stars. To give one instance only, at the Santiago station alone 48 spectroscopic binaries have been announced up to May, 1909, and to work up these binary systems adequately and compute their orbits would necessitate at least three years' work. One in every five or six of the northern stars examined has proved to be a binary, and nearly one in five of the stars observed by Prof.

Wright during the first two years and a half of the work of the D. O. Mills expedition. The discovery of so many spectroscopic binaries has greatly complicated the problem of determining the solar motion; moreover, several other complexities have of late been added to the analysis of the results. Recent investigations of the proper motions of the stars made by Kapteyn, Eddington, Dyson, Schwarzschild, and others, have shown that our universe is probably complex rather than homogeneous in respect to its structure, for there seem to be at least two fairly well marked directions of motions among the stars as a whole.[1] Moreover, Monck and Kapteyn have pointed out that a considerable majority of stars possessing marked proper motions belong to those spectral types which show numerous lines of various elements, while the hydrogen and helium stars are relatively fixed in space. In connection with these facts a further complexity is brought in on the spectroscopic side through the unfortunate circumstance that it is not possible to derive accurate velocities for many of the hydrogen and helium stars, because of the wide and hazy character of their spectral lines. A simple solution will then perhaps be insufficient, on the assumption that all the velocities arrange themselves according to the probability curve; it would seem that a satisfactory conclusion can only be reached by a very careful combination of spectrographic results with due regard to all that the astronomy of position can give us with reference to "star-drift," proper motions, and variation of proper motion with type of spectrum.

Work on the determination of radial velocities has recently been inaugurated at the Observatory of the Cape of Good Hope, so that these two observatories, that at the Cape, and the D. O. Mills expedition, have to themselves this rich and still only partly explored field, while in the Northern Hemisphere some 10 observatories are at work on problems more or less allied to the determination of radial velocities.

In figure 1 are shown the locations of the principal observatories of the world; the cut is that given by Stroobant in Les Observatoires Astronomiques et les Astronomes, Bruxelles, 1907, with the addition of a few recently established stations. The map shows, better than any description or tabulation, the overwhelming disproportion in the number of astronomical foundations in the Northern and Southern Hemispheres.

Sufficient has been said to point out the great richness of the skies of the Southern Hemisphere as a field for the working astronomer, and note has been made of some of the lines of work in which there are great untouched regions awaiting the explorer. Numerous other

[1] Recent investigations by Dr. Campbell, based upon his radial velocities for over 1,000 of the brighter stars, give but little support to the two-drift hypothesis.—AUTHOR, May 9, 1911.

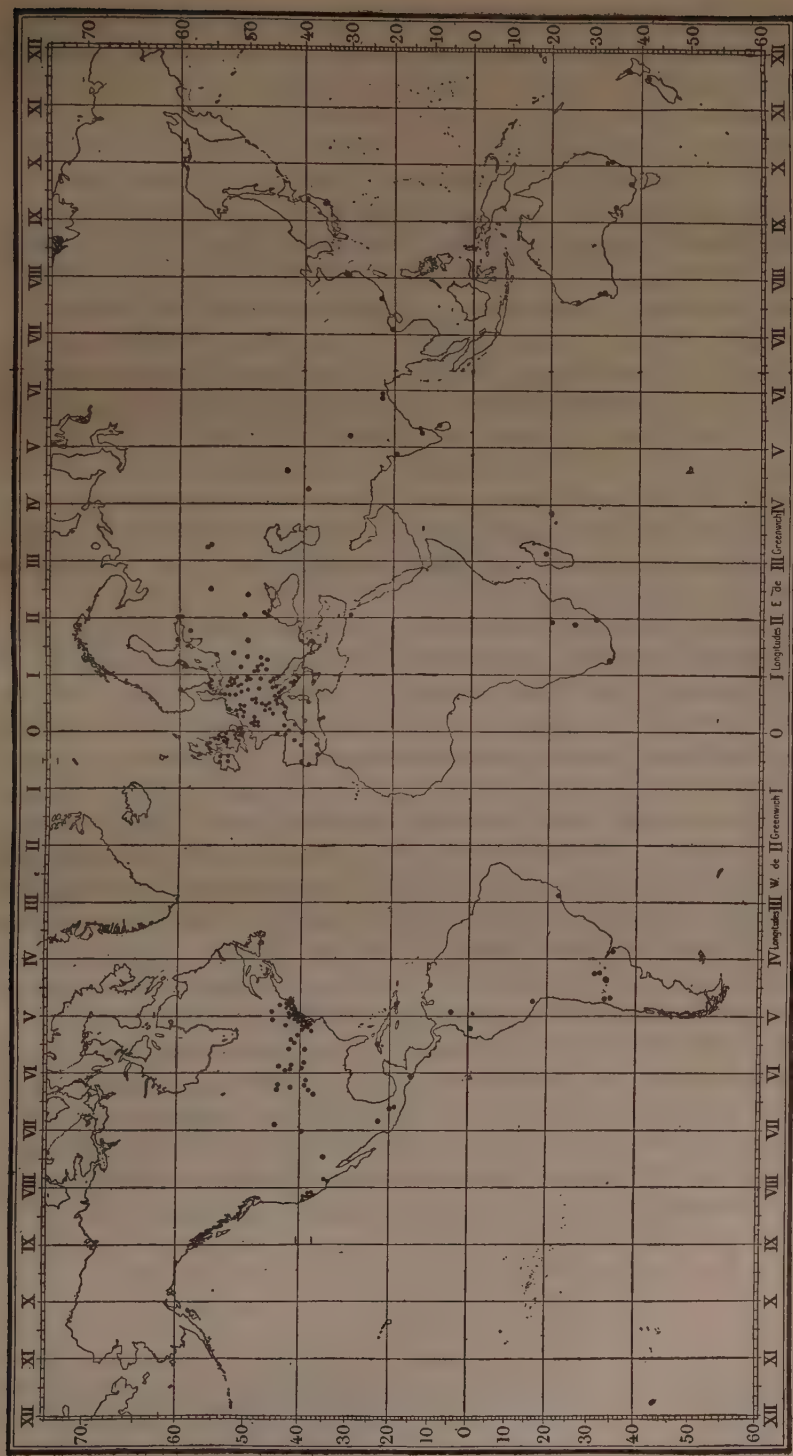


FIG. 1.—Distribution of the principal observatories of the world.

points in which there is need for work in southern skies could easily be pointed out. Much work still remains to be done by those who are not possessed of powerful instruments in the study of the brighter variable stars and meteor radiants. Excellent photographs have been made with the Bruce refractor at Arequipa, but the field of southern nebular photography with reflecting telescopes is almost untouched as yet, and there is no more urgent need for the astronomy of the Southern Hemisphere than the establishment of a large reflector to continue for the southern skies the work done by Roberts, Keeler, Perrine, and others on the northern nebulæ and clusters, for the study of faint variable stars, for parallax investigations, and many other allied lines of research. A program of nebular photography has been inaugurated with the new reflector at Helwan, Egypt; its southern limit, however, will extend only to —40°. The day must come, also, when there shall be established at some favorable point in the Southern Hemisphere a large solar observatory to carry on solar studies and investigations of the sun's constant of heat in the southern summer season, thus supplementing the work of the northern solar observatories.

Above all, so few are the workers in this southern field compared with the men and the instruments attacking the problems of the northern skies, that some scheme of cooperation among southern observatories seems imperative, each one to devote its attention to some one line of work or some definite zone. Prof. Cooke, of Perth, has recently pointed out the disadvantages arising from scattered and unsystematic observations in meridian circle work, and has announced that for the future all the efforts of Perth Observatory in determining stellar positions will be concentrated upon the zone from south declination 31° to 41°. Some such plan of cooperation and delimitation seems essential for the future progress of astronomy, and more particularly for the astronomy of the Southern Hemisphere; as Prof. Kapteyn has pointed out, the scope of this science to-day, with its millions of isolated units demanding study, is too vast for the combined efforts of all the observatories of the world, and he has accordingly suggested the well-known plan of limiting future studies to certain relatively small "selected areas," a plan which promises to be the best method of extending our finite knowledge in a realm that is practically infinite.

THE PROGRESSIVE DISCLOSURE OF THE ENTIRE ATMOSPHERE OF THE SUN.[1]

[With 4 plates.]

By Dr. H. Deslandres, *Membre de l'Institut.*

The sun, to which this conference is devoted, is a superb subject for study. Everyone realizes more or less clearly that the destinies of our earth are closely bound with those of the sun, and so we ought to know its real nature, its total radiation, its variations—in a word, its precise and complete action upon our globe. Face to face with the sun, our dependence upon it is absolute, and was recently summarized tersely by one of our French statesmen, now minister of finance, from whom I had asked a special appropriation for solar researches at the Observatory of Meudon, where I am director. At first he refused, alleging the continuous increase in the public disbursements. Then, as I insisted, he said, "Yes; you are right; the sun is master of us all; we must do something." And so the Observatory at Meudon was enabled to add to its ordinary means an amount, truly very small, but which came opportunely and aided greatly in the prosecution of researches the results of which I now present to you.

The study of the sun to-day requires a costly installation, complicated apparatus, and a personnel specially apt in physical as well as in astronomical observations. Since the sun lights the entire globe and ripens all our crops, it seems but natural that every man should direct his energies to the study of the sun. And with this in mind I proposed, some years since, to the Astronomical Society of France, that there be enacted a special and universal tax, only one cent per capita, for the study of the sun. This would have assured a continuous record of the sun and its changes not yet realized and, accordingly, a more profound knowledge of this star. But as our taxes are

[1] Discourse delivered in French at the Royal Institution of Great Britain on Friday, June 10, 1910. Translated by permission from the author's separate, printed by Royal Institution of Great Britain, London. Published also in Nature, London, Vol. 85, Jan. 26 and Feb. 2, 1911.

constantly increasing, this one, though very small and just, will probably be set aside. Still, it must be said, civilized man of to-day, and he of the city especially, thinks little about the sun; he notices it less than primitive man and the savage who had neither watch nor almanac. The carrying out of my idea must be reserved for future citizens and for a social state more perfect than our own.

This recourse to the Government or to associations of men is a French custom. It would be better to proceed as the English do, and appeal to private support, to the initiative of enlightened, generous individuals. In this way the Royal Institution was founded which has seen mature so many beautiful discoveries and so many illustrious scientists. This good example should be followed by all. We know how liberally it has been followed in America, where the greatest observatories and especially those devoted to the study of the sun have been due to private munificence.

Indeed, during the last 50 years, thanks to great discoveries, thanks to the support of our Governments and private patrons, the study of the sun has made remarkable progress. Little by little, astronomers have developed for it a zealous and permanent organization, and have extended their study to the entire and hitherto inaccessible atmosphere of this star.

The principal discovery was the periodic variations of the sun spots, variations which are also undergone by the brilliant faculæ of the surface and, indeed, by all of its far-extending atmosphere. The sun in its entirety undergoes a great periodic variation; and what is yet more interesting, this variation extends to the earth and affects its magnetic elements.

This connection of solar phenomena with the earth is of capital importance. It implies almost necessarily a novel, special action exercised by the sun upon our globe; whence comes the practical popularity which solar research now enjoys. Following the discovery by Sabine and Lamont of the coincidence between the earth's magnetic variation and the variation of the sun, the English have given very great attention to the study of sun spots; and they were the first to establish the photographic registration of the spots and the magnetic elements at various places on the earth. The collection of all these records in one observatory, where they were accurately compared, followed. The works of Ellis and Maunder relative to these discoveries are well known. In this connection it is fitting to mention the researches of Lockyer and Schuster, who have recently noted variations of the spots in periods greater and smaller than the principal cycle of 11 years.

The action produced upon the earth by the sun is generally attributed to the sun spots, but it may as well have its cause in the solar atmosphere, which undergoes the same variation; whence comes

the necessity of studying and examining this with care. For nearly 20 years I have studied the entire atmosphere of the sun, and to-day I place before you the most recent results which have been brought to light relative to the upper layers of the solar envelope until recently unexplored.

1. THE ATMOSPHERE SEEN DURING ECLIPSES NEAR THE EXTERIOR EDGE OF THE SUN.

The atmosphere of the sun is first revealed to man about the edge of the disk during total eclipses. It then forms a luminous ring that stands out from the now dark background of the sky surrounding the lunar disk, equally black. Stretching out beyond the moon and the solar edge, it consists of two distinct portions: One, the narrow, brilliant, rose-colored chromosphere, with its prominences, also rose colored; the other, the fainter and more extensive corona. In what immediately follows we shall consider especially the chromosphere and the prominences. This luminous ring, visible at eclipses, is ordinarily hidden by the much more brilliant illumination of our sky. The screen which masks it is luminous; in order to annul this screen the English astronomer, Sir Norman Lockyer, in 1866, was among the first to have recourse to the spectrum, supposing what seemed probable, that the solar atmosphere is gaseous. This was one of those strokes of genius that have since become so fruitful.

The eclipse of 1868 showed, indeed, that the rose-colored prominences are composed almost wholly of incandescent hydrogen which, under the influence of the electric spark, emits radiations already well known in the laboratory, and especially an intense red ray, designated as $H\alpha$. After the eclipse, Janssen in the Indies and Lockyer in England rediscovered the chromosphere and prominences of the eclipse with the assistance of the spectroscope and this bright red line. This result was justly received with enthusiasm, for this method, at once simple and fertile, has now been employed for 40 years in daily observations of the chromosphere and the positions and forms of the prominences. This study is even more captivating than that of the spots, for the prominences have the most varied and rapidly changing forms. They appear at all latitudes and follow the same 11-year period as the spots, although it is true the duration of the maximum is longer.

The spectroscopic study of the solar border, carried on at ordinary times or, still better, at eclipses, has brought us knowledge not only of the chemical composition of the chromosphere, but also the minimum height to which each vapor extends as estimated by the length of the corresponding line in the spectrum.

Speaking generally, vapors of low atomic weight rise to the greatest heights; such is the case with hydrogen and helium. With

these gases the spectrum line which indicates the greatest height is the red one, $H\alpha$, of hydrogen; the other lines of hydrogen show lesser heights and diminish in brightness from the red to the violet end of the spectrum. But reaching to the greatest heights of all are the gasses corresponding to the very brilliant violet lines, H and K, which are emitted by the compounds of calcium. As the atomic weight and density of calcium vapor are relatively great, this seems strange; it is easily explained, however, following the suggestion of Lockyer, by the dissociation of calcium in the sun and in the electric spark in our laboratory. The H and K lines, in all respects exceptional, are very bright at the solar edge, assuring the easy photographing of the prominences with ordinary photographic plates.

On the other hand, the heavy vapors which are much more numerous extend up but a short distance into the atmosphere and are not easily seen except at eclipses. They form the lower, relatively very brilliant layer of the chromosphere, called the reversing layer.

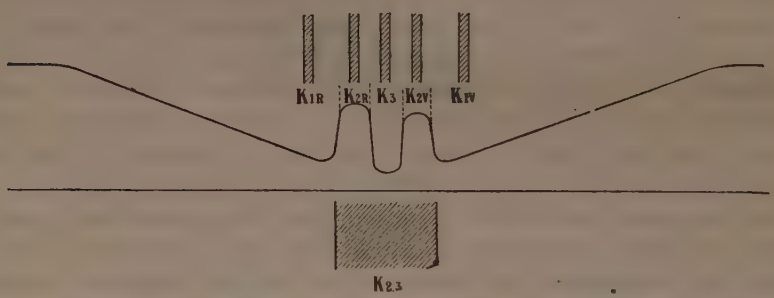


FIG. 1.—Curve of the intensities in the solar spectrum in the neighborhood of the broad dark K line. The cross-hatched sections show the positions of the slits of the different spectroheliographs.

2. THE CHROMOSPHERE PROJECTED ON THE DISK—THE AVERAGE LAYER.

Such are the principal results obtained by the method of Lockyer and Janssen. They are truly wonderful, but in certain respects incomplete. They tell us only of that part of the chromosphere exterior to the edge of the solar disk and even there only about the lighter vapors at some distance from the limb. The part within the edge, projected upon the disk, and fifty times more extended in area, eluded our vision. But, since from 1892 to 1894, even this gap in our knowledge has been covered by an absolutely general method which reveals all the vapors, both heavy and light, and their successive layers in the entire hemisphere turned toward the earth.

At the border of the sun the lines due to these vapors stand out bright upon the continuous spectrum of the sky; on the disk they appear dark, and the continuous spectrum which then serves as their background is that of the sun itself which is much more brilliant, so that the difficulty of seeing these lines is far greater.

That the H and K lines of calcium are an exception to this rule was announced simultaneously in February, 1892, by Hale and Deslandres. These dark lines are very broad, indeed the broadest in the solar spectrum; but wherever on the solar surface there is a facula, they are reversed; in other words, there appears a bright line through the center of the broad dark line, and this bright line is itself double and stands out therefore as the lines of the prominences do outside of the limb. (See fig. 1, which shows the K line and its components K_{1V}, K_{2V}, K_3, K_{2R}, K_{1R}.)

This result was obtained by Hale with the spectroheliograph, a new, somewhat complex contrivance that isolates a certain radiation with a second slit and by the movement of the first slit over the sun's image furnishes a monochromatic image of the sun. I, myself, have

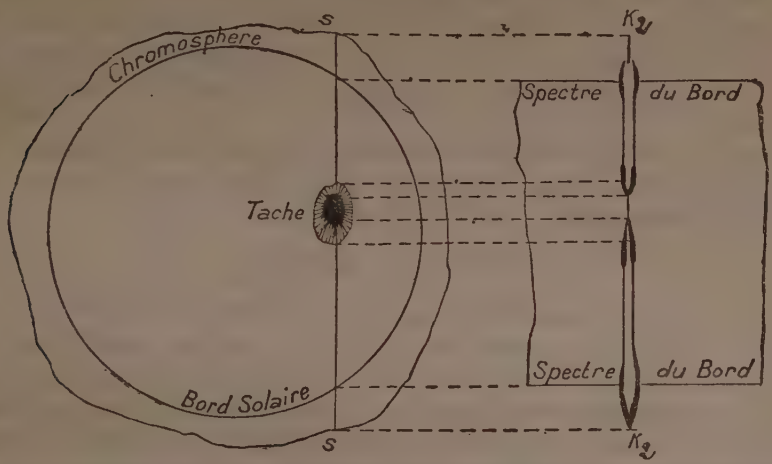


FIG. 2.—(Schematic) ss, section of the sun made by the slit of the spectroscope; the chromosphere and the spot are very much enlarged; bright K_2 line, attributed to the calcium vapor and which appears in the middle of the broad dark K line of the ordinary spectrum; it is single and narrow above spots and at the upper level of the chromosphere and double at other places, being then divided into two parts by the dark central K_3 line.

employed an ordinary simple spectroscope giving successive sections, though fully recognizing the use of the spectroheliograph.

Meanwhile these two observers were at variance upon an important point. Hale placed these vapors thus revealed in the facula itself, below the surface, while I placed them, on the contrary, above in the atmosphere. The ordinary spectroscope furnishes all the data necessary for the solution of this question. Accordingly, in this respect it is superior to the spectroheliograph.

The double K_2 line is bright not only over the faculæ but at all other points over the disk where it is present—weaker, it is true, and more difficult to detect. The bright, double K_2 line is always sharp just within the limb, and is prolonged beyond the edge of the disk as a double, bright line. (See fig. 2, which shows plainly the

appearance of the double K_2 line at the border of the sun as well as over a spot.)

Since the K_2 line, exterior to the limb of the sun, corresponds to just what we have actually defined as the chromosphere, then we must conclude: The photograph of the sun taken with the K_2 line with the spectroheliograph represents the whole solar chromosphere projected on the disk.

Besides these images of calcium made in Paris in 1894, which were the first exact images of this vapor, show the bright regions of faculæ larger than on the ordinary photograph of the surface, as well as smaller bright regions now called flocculi. These flocculi are present at the pole as well as at the equator. I have confirmed their presence at the pole during the years of a sunspot minimum as well as during the whole 11-year period.

The bright K_2 line remains double beyond the edge for some 4″ or 5″ of arc, and as the chromosphere at the edge has a height of 10″, we may say that our photograph represents the mean chromosphere.

Finally, while the first spectroheliographs were obtained in America, in France was discovered for the first time the whole chromosphere of the sun.

3. LOWER CHROMOSPHERE.

But we may proceed still further. In 1893, I stated that this isolation with the spectroheliograph of an ordinary dark line produced an image of the corresponding vapor; and in 1894, I isolated, with a small spectroheliograph of low dispersion constructed at Paris, the fading edges of the K line called K_{1R} and K_{1V} and the neighboring strongest dark lines due to aluminum, to iron and to carbon. The spectroheliogram obtained differed from those taken with the K_2 line. The spots, at times hidden in the K_2 image, have here their umbræ and penumbræ perfectly sharp and the regions of faculæ both at the edge and at the center though less extensive than in the K_2 image. Indeed, this new image is intermediate between that of the surface and that of the mean chromospheric layer as shown by the K_2 photograph. It gives a picture of the entire reversing layer now obtained for the first time.

I showed, also, that a still greater dispersion would allow the isolation of the much more numerous finer lines, and especially the narrow black central K_3 between the two components of K_2. The K_3 line corresponds to the upper layer of the chromosphere. This method becomes thus absolutely general; it will furnish views of all the solar vapors indicating as well the successive superposed strata whenever the spectrum lines can be divided into distinct parts as in the case of the broad K line.

Now, the number of solar lines amounts to some 20,000; and according to Jewell, all the solar lines show more or less the special characteristics of the typical line of calcium. The new field open to investigation is evidently very broad.

4. RECENT RESEARCHES—A GREAT SPECTROHELIOGRAPH OF NEW TYPE.

The program of researches laid out in 1894 was accordingly very extensive. It was carried out in part during the following years, and the actual progress was marked, if not very rapid.

In 1903 Hale and Ellermann took up the study in the black lines with a spectroheliograph of greater dispersion, and after 1906 continued the work at Mount Wilson with yet more powerful instruments. They have obtained beautiful pictures and a whole series of new facts. With the lines of the reversing layer the results are practically the same as those obtained in 1894. But the hydrogen lines, and recently the $H\alpha$ line especially, have shown new and very curious phenomena, which we will describe in detail shortly.

However, the dispersion employed has been only moderate; though they have isolated a much greater number of lines than in 1894, the finer lines have not been used; and indeed in each case they have used the entire lines, making no distinction of the separate portions and therefore of the separate layers of the vapors. Their images have resulted from the mixture of the several distinct ones due to the several layers.

I assumed the task of filling this gap and thus completing the program of 1894, isolating the upper strata hitherto unrevealed. Becoming director of the Observatory of Meudon in 1907, I was able to apply to this task the resources of the observatory, and here the special grant already mentioned proved very opportune. In short, it became possible to construct a great spectroheliograph having a dispersion as great as that of Rowland's large spectrograph and a special building for its protection.

This building consisted of a large chamber, 22 meters by 6 meters; its roof was of stone and earth, assuring the constancy of the temperature within. It received the light from the sun by way of a coelostat placed south of the building, and constructed from some old transit-of-Venus apparatus and an old objective of 0.25 meter aperture and 4 meters focus. These pieces, though mediocre, were used for the sake of economy. The spectroheliograph, on the other hand, was of a novel type and presents several interesting features. It is somewhat complicated, at least in design, for it really consists of four different spectroheliographs grouped about the same collimator. The first is of three prisms, two slits and a camera 3 meters long, giving an image of the sun 85 millimeters in diameter; the

second uses a grating, two slits and a camera of the same length as the first; the third has an arrangement differing from the two preceding; finally, the fourth, the most powerful, has three slits and prisms and grating. It consists first of a spectrograph having a camera of 7 meters, and, as in the classical apparatus of Rowland, allows the isolation of very fine lines. But its ordinary solar image would require too long an exposure. It is therefore received by a second spectrograph which reduces it to the desired size and eliminates the diffused interior light. The final image of the sun is of any diameter desired; and by means of a special contrivance it shows the entire solar disk, a condition not fulfilled in other spectroheliographs of great dispersion. The customary diameters of the sun's images are 6 and 4 centimeters.

This apparatus, with the two spectrographs, has a total length of 14 meters, and under these conditions rests stationary. It is, indeed, the first spectroheliograph in which all the parts except the photographic plate remain at rest. The movable parts, the plate and the astronomical objective, are put in motion at the desired rate by synchronous electric motors and transformers for special speeds.

The agreement of the movements is assured by electrical means, which do not depend upon distance, and this arrangement is presented as a general solution of the spectroheliographic problem. Each of the four spectroheliographs has its special advantages, and the passage from one to another may be made in a few moments. The observer has thus at his disposal varied means for his investigations. In a general manner the spectroheliograph of two slits and a length of 3 meters has a large image, rich in detail. The three-slit spectroheliograph of 14 meters gives, with a longer exposure, a smaller image, but one much more pure (that is, more monochromatic); it allows the isolation of the finest lines.

The researches with this apparatus have been made by a young astronomer of this observatory, M. d'Azambuja, whose name is associated with mine.

5. THE DISCLOSURE OF THE UPPER K_3 LAYER OF CALCIUM.

In 1908 we were able to isolate the narrow dark central line, K_3, of calcium, and therefore the upper stratum of that vapor. Figure 1, which shows the K line and its components, will indicate the progress accomplished. Until now the spectroheliograph used had isolated the ensemble of the two bright lines (K_2), which include K_3; the slit width was then ninety one-hundredths Ångström. The resulting image, called by us the K_{23} image, was a composite of the layers K_2 and K_3, the much brighter K_2 layer predominating. Now with the great spectroheliograph we are able to isolate easily with slits of

three one-hundredths Angström or greater either the K_2 line or one of the components of K_3, thus obtaining very pure images of each corresponding stratum free from all extraneous light. The corresponding slit widths are crosshatched in section in figure 1.

The vapor of calcium, which beyond the limb rises higher than all the other vapors, thus shows us three distinct strata, and if to these we add the ordinary surface of the sun we have four layers which are interesting to compare.

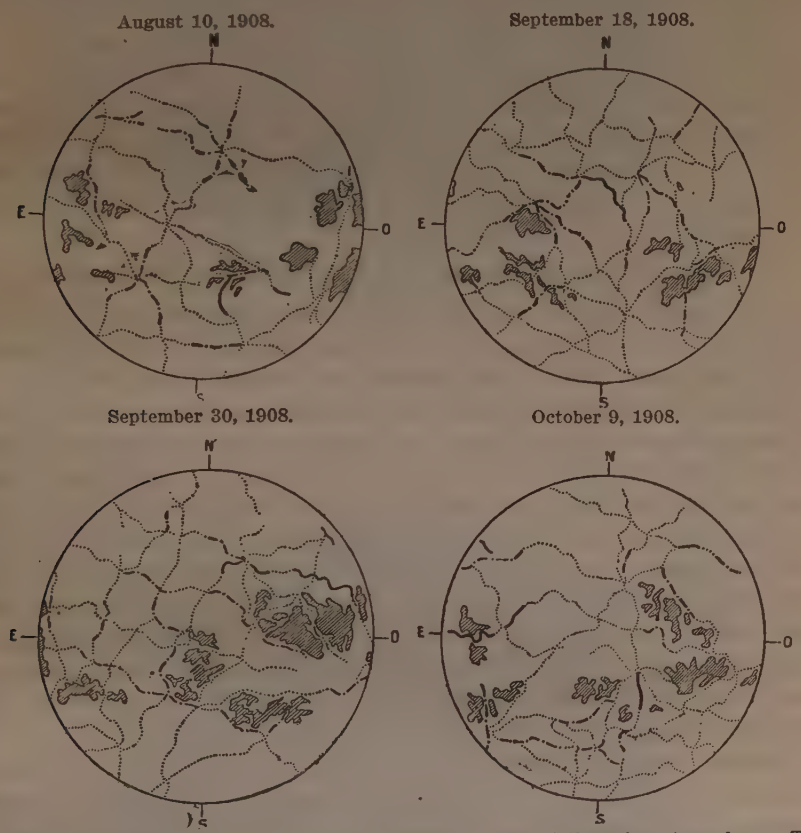


FIG. 3.—Network of alignments noted in the upper layer of the solar atmosphere. The full dark traces correspond to the continuous and very sharp dark lines called *filaments;* the discontinuous traces to the similar lines though less sharp and the dotted lines to those still less visible and often broken. The hatched places are the larger regions of bright faculæ.

As we rise above the surface of the sun the faculæ, or bright regions, grow progressively in extent and relative brightness. The average-sized flocculi increase, although the small ones disappear or become scarcely visible. There results a certain aspect of the K_3 layer which at once distinguishes it from the K_2 layer photographed in 1892. (See the two spectroheliograms in K_3 and K_2 of the 18th of September, 1908.) I would also add that the peculiar network (reseau) of flocculi, called by me in 1894 the chromospheric

reseau, and often formed over a considerable area, composed of polygons touching each other at their sides and corners, is in general more distinct in the upper layer.

On the other hand, the black spots which are the principal characteristic of the surface diminish progressively as we go above the surface and often disappear.

Yet, further, there appear dark lines not seen in the lower layers, lines often very long and called by me filaments. Generally the filaments have extensions from each side reaching to the limb neither so dark nor so sharp, which I call "alignments." The ensemble of filaments and alignments form a definite network over the solar disk. They are a new phenomenon characteristic of the upper layer. Here the filaments have the same importance as the spot at the surface. They persist, like them, during several rotations, and like them also are the seats of special disturbances which are accompanied by prominences.

6. THE DISCLOSURE OF THE UPPER H_α LAYER OF HYDROGEN.

In my first studies I likened the spots to depressions ("lows") or cyclones in our atmosphere and the filaments to anticyclones. I will come back later to this comparison, which I will develop.

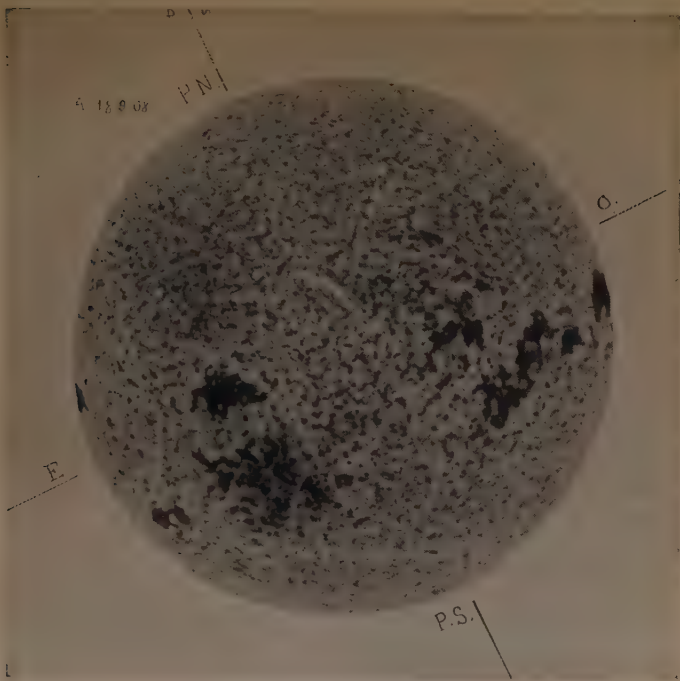
During the following year we (d'Azambuja and I) used this same apparatus in the study of the hydrogen lines, and especially the the red $H\alpha$. Hale and Ellermann had already isolated these lines with the spectroheliograph, obtaining very curious results. In 1893 they noted that in the $H\beta$, $H\gamma$, and $H\delta$ spectroheliograms the faculæ were no longer bright with reference to the background, as in the calcium images, but, on the contrary, are often dark. With H_α, isolated in 1908, they found all about the spots a series of fine demarcations, giving the impression of whirls, and which Hale has described here at a special meeting. Indeed, these $H\alpha$ images are beautiful and abounding in fine details.

However, these American $H\alpha$ images were obtained by the isolation and use of the whole dark line. I stated in 1908 that they must be composed of the mixture of the two or three images belonging to different strata. For, according to Rowland, the $H\alpha$ line is doubly reversed like the K line, due to calcium although more feebly. Its width, including the shading edges, is 1.24 Ångströms; without them, 0.90. We would, therefore, expect somewhat different results as different portions of the line are isolated.

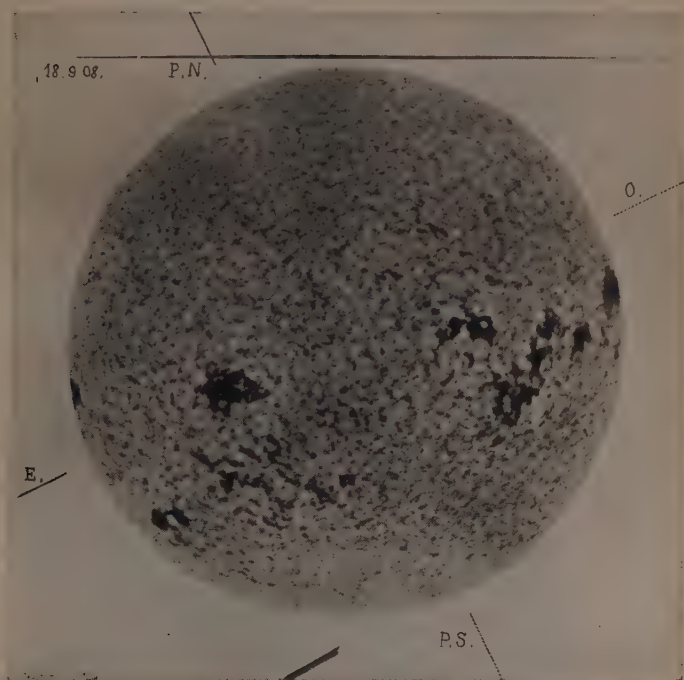
This we have already clearly shown to be true, and indeed, contrary to all our expectations, the differences existing between the various hydrogen images are greater than for calcium.

The exact results are as follows:

When the shaded portion close to the edge of the line is used, corresponding to K_1 of calcium, at a distance from the center of the



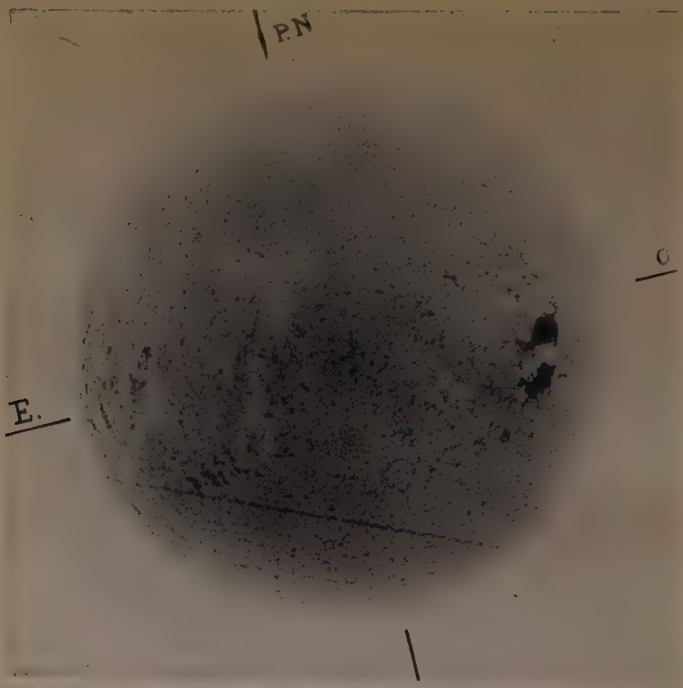
Upper K_3 layer of calcium.



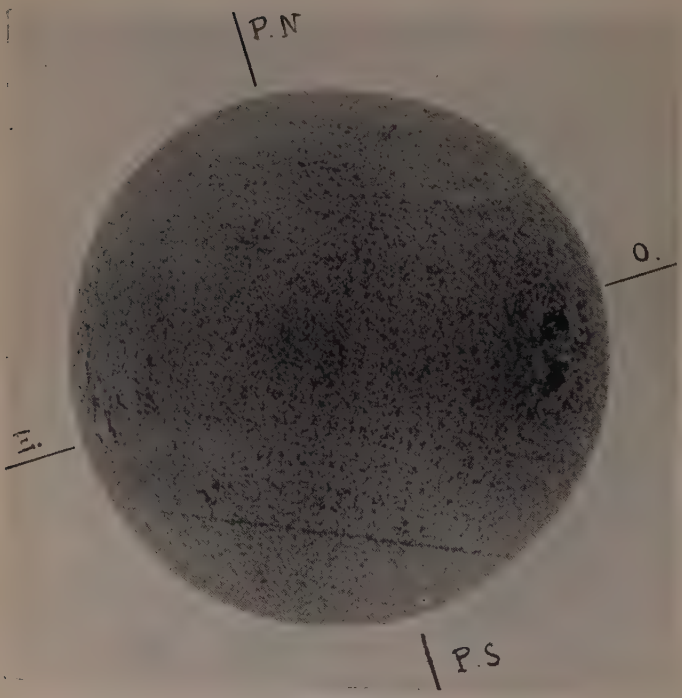
Mean K_2 layer of calcium.

SPECTROHELIOGRAMS OF SEPTEMBER 18, 1908.

(Negatives.)



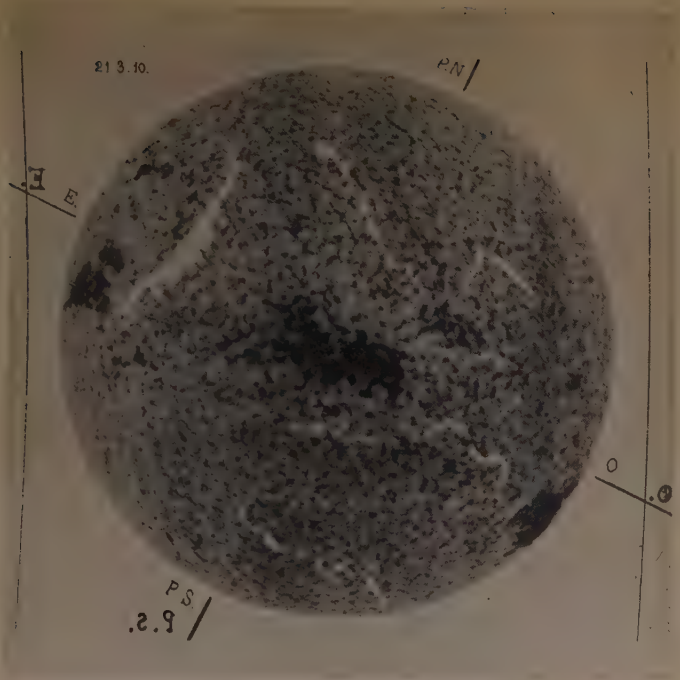
Upper layer of hydrogen.



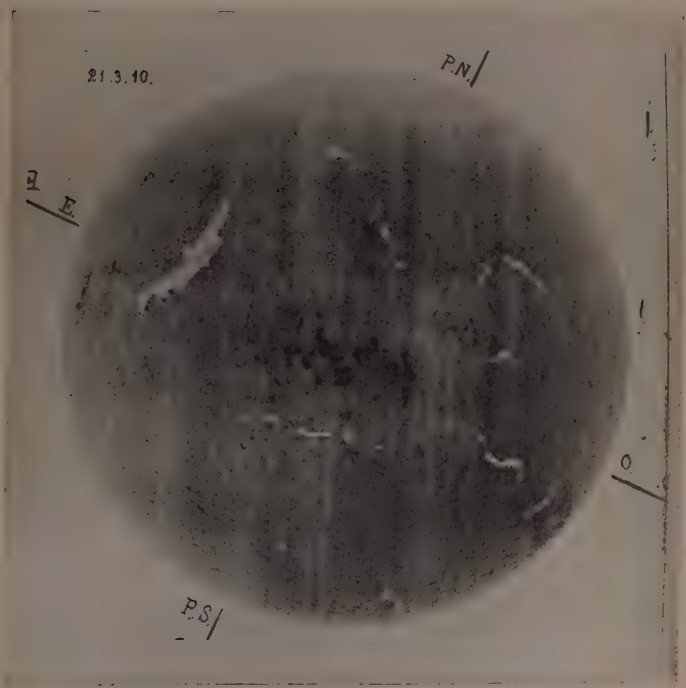
Mean layer of hydrogen.

SPECTROHELIOGRAMS OF SEPTEMBER 11, 1909.

(Negatives.)



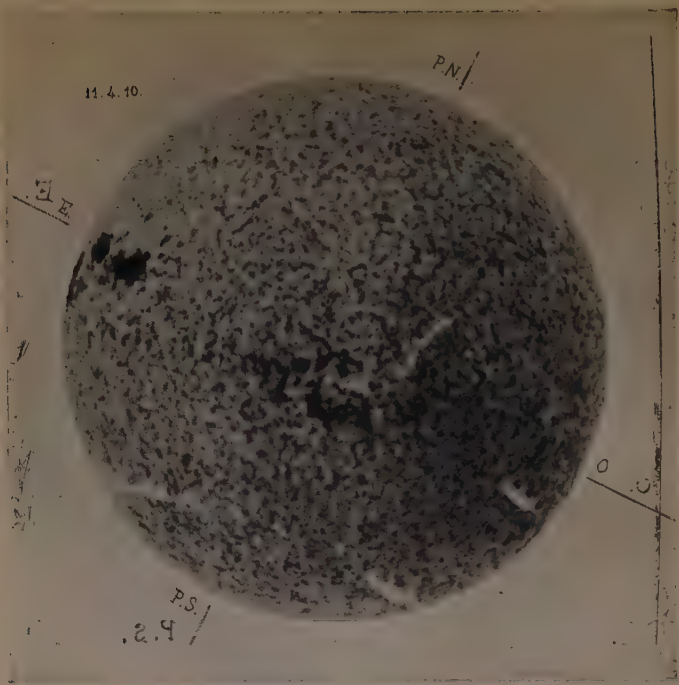
Upper layer of calcium.



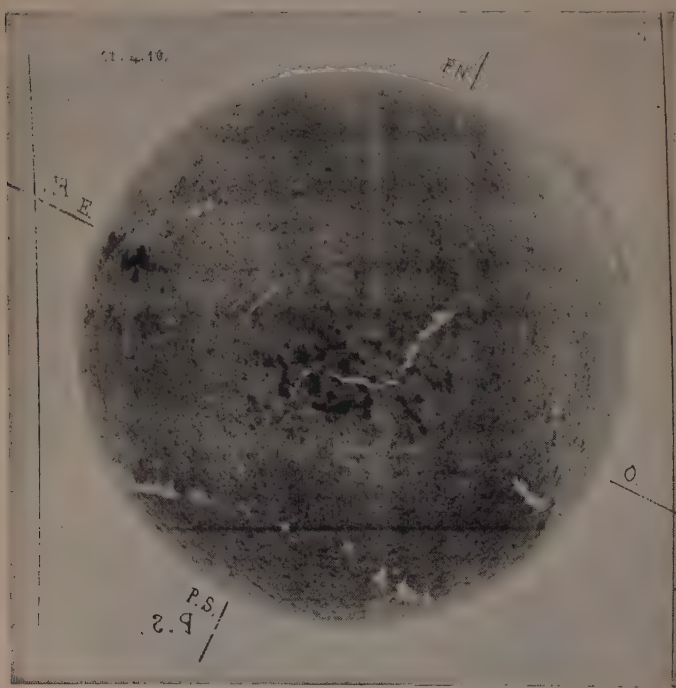
Upper layer of hydrogen mixed with a portion of the mean layer.

SPECTROHELIOGRAMS OF MARCH 21, 1910.

(Negatives.)



Upper layer of calcium.



Upper layer of hydrogen mixed with a portion of the mean layer.

SPECTROHELIOGRAMS OF APRIL 11, 1910.

(Negatives.)

line amounting to between forty-seven one-hundredths and sixty-two one-hundredths of an Ångström, we get the result of 1893; that is to say, the regions of faculæ appear black relative to the background.

When the middle of each side is used at a distance of from ten one-hundredths to forty-two one-hundredths of an Ångström from the center, the result is entirely different. It shows the principal characteristics of the spectro-heliograms taken in America in 1908 and particularly the groups of small lines which Hale has called "solar vortices."

Finally, with the center of the line we get a third, yet different, aspect from the other two, much paler and simpler and corresponding to the upper layer of hydrogen.

Now, and this point is important, the new image shows the dark filaments of the K_3 layer of calcium. As to the regions of faculæ, they are bright, never dark; they cover a smaller region than with the K_3 stratum and correspond to the maxima of brightness of the similar regions in the K_3 stratum, maxima which differ from those of the K_2 and K_1 strata. The darkest and the brightest parts are the same. (See the annexed pictures taken with K_3 and with $H\alpha$ the 11th of September, 1909, and the 21st of March and the 11th of April, 1910.)

And yet further, we have isolated the various parts of the blue $H\beta$ line of hydrogen, showing a lower elevation in the solar atmosphere than the $H\alpha$ line, and so obtained images which show almost exclusively the dark regions of faculæ such as we found in the shaded portion of the red $H\alpha$ line and which therefore correspond to a low level.

Finally, we are led to conclude that hydrogen gives, like calcium, at least three distinct superposed strata which are now for the first time clearly distinguished.

Now, in what just precedes I have treated the different portions of the same line and the different corresponding images by the ordinary laws of emission and absorption by gases, admitting naturally that the density of the gas and the width of the corresponding line diminish as we go upward in the solar atmosphere. Now, the theory of anomalous dispersion has been brought forward as coming into play here, and, at least in part, explaining the peculiarities of these images. But it seems to me that anomalous dispersion, while, of course, to some extent it must come into play, does so only to a minor extent and may be neglected in this preliminary study. The real reasons for making such an assertion would take too long to develop here. However, anomalous dispersion has been found in the laboratory with the lines H and K of calcium, and recently with the

$H\alpha$ line.[1] But as the center of the line does not suffer anomalous dispersion, this theory can not apply to the images of the upper strata with which we are now interested.

The black filaments which are found similarly in both calcium and hydrogen are in fact a very characteristic element of the upper stratum. Hale had already a glimpse of them in the earlier, really composite spectro-heliograms taken with K and $H\alpha$ light, and noted them under the name of long dark flocculi and suggested that they very probably belonged to the high strata. Indeed, under such conditions one may often obtain the most important filaments which appear as very broad, dark lines. But for a complete knowledge of the filaments and their properties we must have recourse to the images solely of the upper stratum.

Another important element of the upper strata is the bright regions of faculæ which are found at the same positions as on the surface though of different form.

To sum up, if we examine the four layers formed by the surface and the atmosphere of the sun, the brightest portions are above the faculæ. But the darkest regions are placed very differently at the surface and in the upper strata. Below they occur in the spots; above, in the filaments which occupy a total black surface greater than that of the spots. The area covered by these filaments should be measured as exactly as that occupied by the spots.

7. RESEARCHES ON THE MEVEMENTS OF THE ATMOSPHERE—AN INSTRUMENT FOR REGISTERING SPECTRUM VELOCITIES.

The black filaments especially attract attention, and indeed justly, for, as we have just said, they have an importance at least equal to that of the spots. What, then, is their origin and what the nature of these long dark lines? An accurate answer is very difficult; it is significant to recall our uncertainty as to the spots which have been studied 300 years. However, with the filaments the inquiry may be more easy. The surface which carries the spot lies between the interior of the sun, which escapes our vision, and the lower complex strata of the atmosphere; on the other hand, the upper layer, with which the filaments are connected, is more free, more disengaged, and may have a structure and movements more simple.

Indeed, at Meudon, several results regarding the filaments have been obtained worthy of note by virtue of a special device developed and used as yet only at Meudon and which is an instrument for registering or indicating spectrum velocities (spectro-enregistreurs des vitesses). This apparatus, used since 1892, was greatly improved in 1907. It reveals, as its name indicates, the radial movements of

[1] Some months after the Royal Institution lecture we found at Meudon that the anomalous dispersion was acting on the edges of the K_3 line; so that the displacement toward the red is increased and the displacement toward the violet diminished. But the image of the center of the line with the spectroheliograph is always unchanged.

the solar vapors by placing side by side small spectra of successive equidistant sections of the solar disk by means of a second large slit and discontinuous, automatic movements. It is a complement to the spectro-heliograph and fully as useful. It tells us besides the radial velocities, the general form of the vapors, and the details of the whole line, particularly the width of the isolated line which is very variable from one part of our star to another. It gives us information at points where the spectro-heliograph fails, for the latter can not with a slit of constant width isolate accurately a line of variable width; in short, it records all the elements which escape the spectro-heliograph and assures an accurate interpretation of the results.

A naked-eye examination of the plates taken with the K line shows at once that the radial movements are in general more noticeable on the filaments than at the adjacent points. Sometimes even all the K_3 lines due to the filament are inclined in the same direction and show a whirl about a horizontal axis as distinguished from that which exists in the sun spots about a vertical axis. But to this movement there succeeds, as with the spots, a relative calm. If then we were to measure with care these displacements and the radial velocities in the K_3 line when the vapor is at the center of the disk we would find that the vapor is rising with a velocity often greater than the velocity of rotation of the sun at the equator (some 2 kilometers per second). This has been verified for several filaments. Aside from the spots and the filaments, the vertical velocities in the upper strata are not insignificant and often of the same order as the equatorial speed of rotation. The magnitude of this vertical motion is less astonishing when we note that the gaseous mass of which the atmosphere is composed lies above an intense furnace of heat.

Analogous measures have been made carefully at the center of the sun on faculæ and flocculi with the reverse result. The vapor here has a contrary direction of motion and descends while in the relatively dark portions around there are ascending currents. Generally at the bright places of the K_3 images of the upper layer the vapor descends; it ascends where the image is relatively dark. That is really logical, for the vapor which goes down becomes compressed and therefore becomes warmer, while that which rises expands and becomes cooler.

This phenomenon, which has already been noted on a great number of plates, is important, for it shows the special structure of the atmospheric strata, indicating that they are divided into convection currents exactly as in the case with liquids heated uniformly at their lower surfaces in our laboratories.

The bright faculæ often cover a remarkable extent of the image and often with sharply formed juxtaposed polygons exactly similar

to the polygons formed by the vortex cells in liquids so well studied in France by Bernard.[1]

Since the vapor descends over the flocculi and rises at the interstices, each one of these solar polygons is thus probably a vortex cell. Other flocculi in the same image show polygons less sharp and less complete and sometimes, although more rarely, of wholly irregular forms.

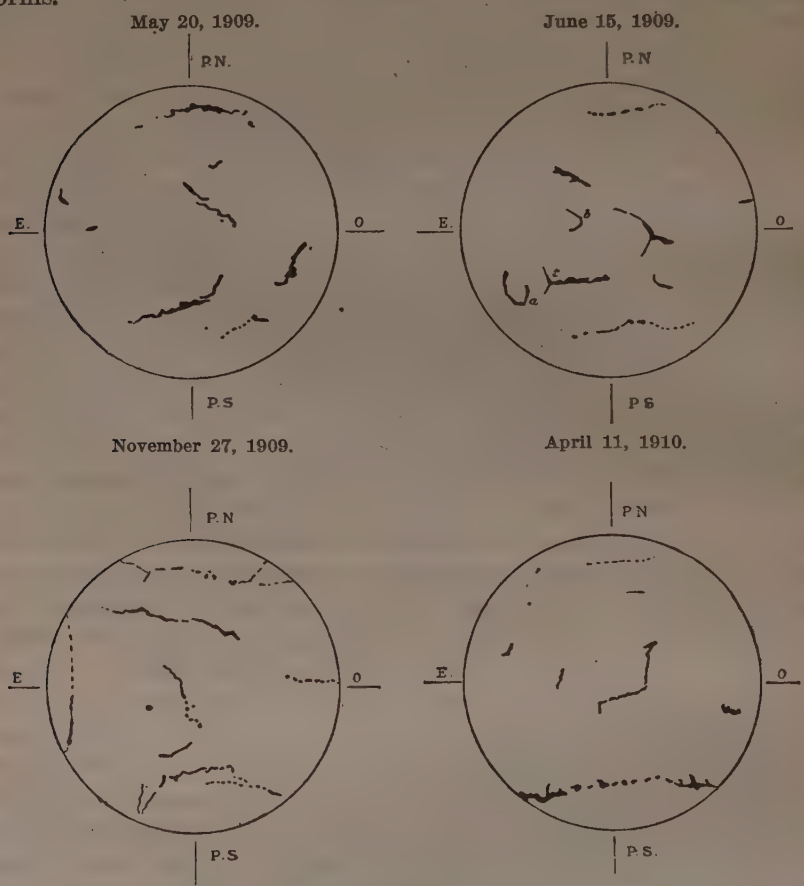


FIG. 4.—Drawings of the upper layer of the solar atmosphere showing the characteristic black filaments and especially the polar filaments. These images, obtained with the aid of d'Azambuja, have been made from the monochromatic pictures of the sun taken with the central portion of the $H\alpha$ line of hydrogen and the K line of calcium. They show only the dark filaments without the alignments. The bright regions above the faculæ have not been represented.

Moreover, the filaments and lines are probably the limits of vortex cells yet greater, superposed upon the preceding in the upper stratum, and of which the spots are the centers. This is in accord with the

[1] This arrangement in juxtaposed polygons is at times very distinct over nearly the whole sun. The K_3 plate of Sept. 18, 1908, shows in the Southern Hemisphere, near the center, several of these polygons joined by their sides and corners; but a larger and sharper image is necessary to show them well.

movements in the stratum next to the spots noted by the English astronomer Evershed. We may easily explain why the spots are pointlike and the filaments linear, sometimes very long. Our problem therefore through these researches has already received some light; it will, it seems probable, be completely elucidated when we have continuous measures of the radial velocities over the whole disk of the sun, unfortunately necessary for a very long period of time.

8. THE DISCOVERY OF THE POLAR FILAMENTS.

I will close with a new phenomenon of the filaments recently recognized at Meudon and already published. The observatory has so far obtained pictures of the upper stratum for more than 20 entire revolutions of the sun, and from them it is possible to study the distribution of the filaments. They appear in all latitudes but at the poles they are generally grouped on a curve, more or less circular, surrounding the pole, although often not along a parallel of latitude. This polar curve of filaments is at times clearly seen at both of the poles, but in general it is distinctly visible only at one and tends to move from one pole to the other. It was particularly distinct and strong during last April at the South Pole. (See the two pictures of Apr. 11 and fig. 1, which show the filaments of four different days.)

These polar filaments are accompanied by prominences and accord with the secondary maxima of prominences at the poles which have already been noted. They may thus be related to the special form of the corona which appears during the minimum of the sun-spot cycle and with the often-noted inclination of the coronal axis to the ordinary solar axis of rotation.

At times the polar curve is accompanied on the side toward the equator by a line of parallel filaments which are reunited to the curve by filaments or lines more or less inclined; and so we find a disposition analogous to that of the bands on the planet Jupiter.

Finally, the polar zone of filaments, where, as we have just seen, the vapor is ascending, may be compared to the zone of spots and faculæ near the equator, where, contrarywise, the vapor is descending. We are led to suppose a great meridian circulation in the upper stratum, a vast general convection current analogous to that which exists in each hemisphere of the earth between the latitudes 35° and the poles.

Time fails, unfortunately, for developing all the consequences of these first observations, but the facts given suffice to show the great interest connected with the study of the upper strata of the solar atmosphere and the necessity of continuing it.

The atmosphere of the sun alone we may observe in its entirety and in its successive layers. Our self-registering apparatus gives in a few moments its general aspect and principal movements. From this point of view it is better known than our own atmosphere, which we may observe only in its lower portions and over a restricted region even with the aid of the telegraph.

The network of convection currents and the curious filaments discovered in the upper stratum may be found also upon the earth, and so the study of the sun may bring us to a better knowledge of our own atmosphere.

RECENT PROGRESS IN ASTROPHYSICS IN THE UNITED STATES.[1]

[With 8 plates.]

By J. Bosler,
Astronomer at the Observatory of Meudon, France.

Americans during recent years have made great advances in astronomy. This science, with its broad horizons and its continued desire for improvements and capital, comports well with the temperament of a people so well endowed for vast undertakings and for all in any way connected with mechanics. To get money for their researches seems second nature, almost a pleasure, to American scientists; as natural to them is the construction and employment of new instruments. We were not astonished, therefore, some months since, on the occasion of the International Conference at Mount Wilson, Cal., in finding for ourselves that they had accomplished great things in this class of undertakings, as well as in many others. It is but just to add that the means placed at the disposal of the astronomers by their many and generous friends were truly proportional to the uses made of these means. What follows will at every step illustrate the beneficent influence of private American initiative.

HARVARD COLLEGE OBSERVATORY—THE SYSTEMATIC STUDY OF THE STARS.

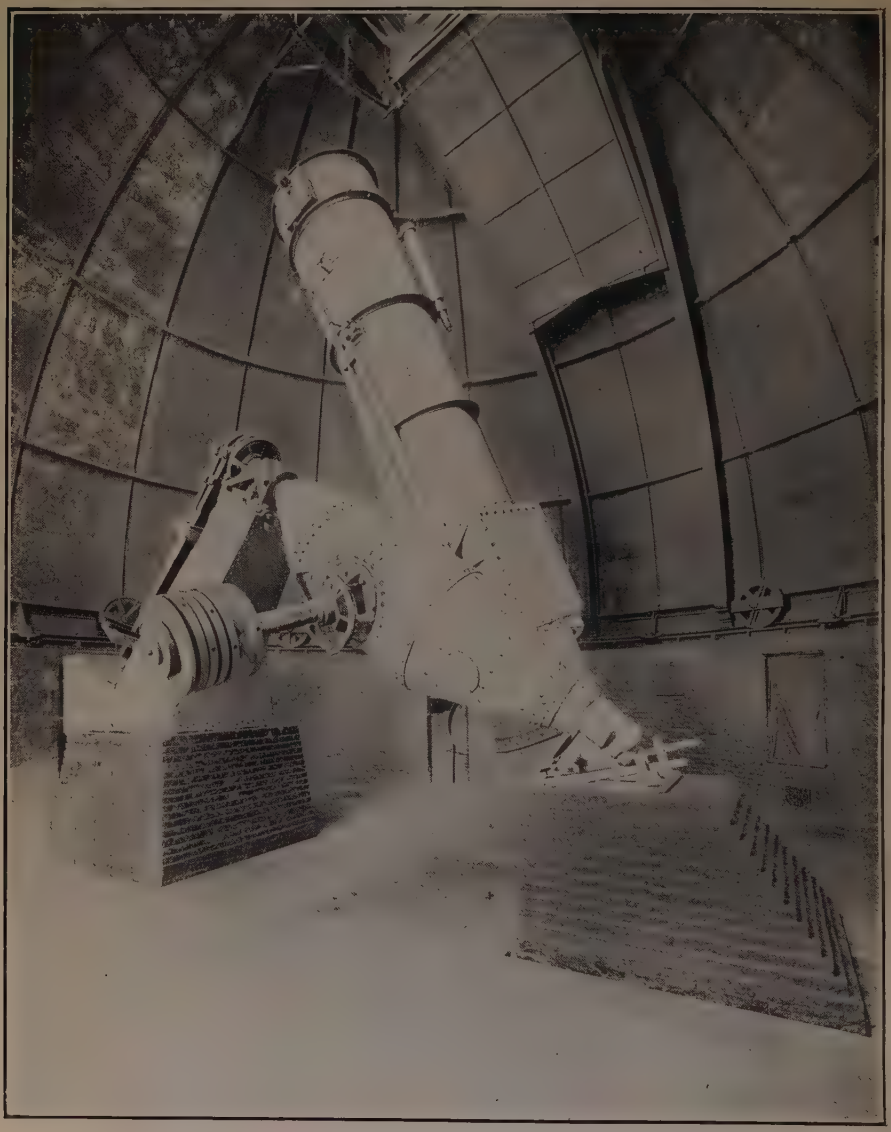
One of the oldest of the scientific establishments in the United States is the celebrated observatory of Harvard College, situated near Cambridge (Mass.), which, during the last quarter of a century, Prof. E. C. Pickering, assisted by his brother, has greatly helped to make illustrious. It is supported not by the State, but by Harvard University, an autonomous institution analogous to the English universities. Situated in the center of New England, near Boston, this observatory is assuredly the least American of all those of the United States; you will not find here those colossal instruments which are the pride of the astronomer of the West; here the methods are akin to our own, and the qualities are the more especially European ones of order and patience, from which so many beautiful results have followed.

[1] Translated, by permisssion, from Revue Générale des Sciences, Paris, 22d year, No. 3, Feb. 15, 1911.

The principal line of researches followed at the Harvard Observatory is the spectroscopic and photometric study of the stars. The observers therefore constantly watch the entire system of stars down to the sixth magnitude, and as much fainter as possible, so that none of them may escape surveillance. In order to study the stars about the southern celestial pole, which for good reasons have been so neglected by most astronomers, the Pickering brothers established, in 1891, an auxiliary station at Arequipa, Peru, at an altitude of about 2,700 meters, and consequently under the best atmospheric conditions for observations. Pickering, with praiseworthy self-denial, sent there one of his most beautiful instruments, the Bruce 24-inch telescope, which he thought would render more service there than at Harvard. We will not dwell on the photometric and spectroscopic catalogues published at Cambridge, nor yet upon the astounding discoveries of spectroscopic double stars, nor the various kinds of stellar hydrogen, and so on, which have been made here in the past. We will limit ourselves to the methods actually in use at this establishment and which, as we have stated, are in themselves of great interest.

Prof. E. C. Pickering personally carries on the stellar photometry and has allowed no detail to escape detection which would lead to precision. The photometer is stationary and placed in a well-shaded place; a siderostat, worked from the interior by an assistant, sends the rays of the star under measurement into the horizontally placed photometer. The astronomer is thus comfortably situated, as at the equatorial-coudé at Paris, with his head enveloped in a mantle of black material; he remains here continuously during the whole evening; the settings, the records, even the readings of the divided scale, are made by his assistant. Mr. Pickering uses his sight strictly for the purely photometric work, assuring himself of his maximum efficiency in the photometric comparisons and avoiding thus a number of more or less systematic errors.

The spectroscopic classification of all the stars of the sky is done principally with the aid of the objective prism of the 11-inch telescope. The equatorial upon which this prism is mounted is in no way unusual except for the electric control, which assures the accurate regulation of the driving mechanism which is kept in perfect synchronism with a controlling pendulum. As this 11-inch apparatus would not have been sufficient, two new ones, both of 24 inches, were constructed at the same time, thus reducing the net cost of each. Nothing more need be said in praise of the objective prism; it is well known how with it, at one exposure, may be photographed the spectra of all the stars visible in a given field. There is much less loss of light than in the use of a slit spectroscope, so that a shorter exposure is necessary. Unfortunately, accurate determinations of wave-lengths can not be made with that system and, despite the most ingenious con-



THE CROSSLEY REFLECTOR OF THE LICK OBSERVATORY.

trivances, because of the lack of a convenient standard for the indication of the wave-lengths, it is difficult to use it for the determinations of radial velocities. It is thought that the use of absorbing screens may do away with this objection last mentioned, now that the substances have been found giving, at ordinary temperatures, fine absorption lines (and not more or less hazy bands). The plates we saw were striking in this respect. This method necessitates, however, a longer exposure.

Great progress has been made lately in the researches on variable stars. Independent of the direct photometric observations which give comparatively few results, several methods have been devised for the discovery of new variables. By means of one of the great portrait objectives of 16-inch (40 centimeters) aperture, which Pickering has had constructed, eight or ten exposures are made in a series on the same plate at intervals of a half hour; those stars are then easily noted, if such exist, which have varied during the four or five hours' exposure. Variables of short period of the Algol type are thus discovered. Another more general procedure in use at Harvard is to take at two different dates two negatives of the same region of the sky; a positive is printed by contact from one of them, let us suppose the second, and superposed upon the original first negative. The stars which have not varied are represented—one of the plates being a little more dense than the other—by black dots surrounded by whitish aureoles (or inversely). The images of stars whose light has varied present a different aspect: if their brightness has increased, they appear surrounded by an aureole relatively brighter than that of their neighbors; if the contrary is the case, the aureole is less marked or perhaps wholly absent. By repeating this several times for each region all the variables existing in these regions may be told almost at a glance, even among the immense numbers of stars not undergoing fluctuations. The value of this method is unlimited and it is admirably adapted to clusters of stars like α Centauri in which 128 variables were discovered at Arequipa. At Harvard this ingenious method has led to the discovery of 2,000 to 3,000 variables, several times as many as have been made known by all the other methods combined.

The objective prism aids also in this class of discovery. We know, for instance, that the variables of long period, of the type of Mira Ceti, for example, contain bright lines in their spectra; on the other hand, these bright-line stars are comparatively rare, so that a star possessing this characteristic attracts our attention at once to its variability.

The organization of this bureau, composed solely of women and which has executed such colossal work, merits our attention. The reader may, however, reassure himself; we shall not detain him long.

We will content ourselves with saying that we Frenchmen, born bureaucrats and believing ourselves without rivals in the routine of administration, would certainly find much to learn here from a practical point of view.

All these researches on variable stars, upon stellar spectra and their classification, may appear to the ordinary reader very monotonous and of very little use; yet they are of great importance for a knowledge of our universe. We should not forget that by means of this incessant comparison these observers can often announce the new stars (novæ) which are so interesting in many ways. And yet, further, a new short-period variable, a new type of stars gives certainly a new clue to the elucidation of yet unsolved problems or what amounts to a new instrument for research in this vast laboratory of the sky where new tools are rarely obtained.

THE LICK OBSERVATORY.

Now, crossing the whole continent from one shore to the other and going to the Lick Observatory, we find a totally different establishment; more grand because of the vastness of the means at its disposal as well as notable for the beauty of its situation. Founded through the generosity of James Lick, a rich Californian, and now under the eminent direction of Prof. W. W. Campbell, the Lick Observatory is situated on Mount Hamilton, at an altitude of 1,400 meters, a beautiful site, although unfortunately somewhat difficult of access despite its nearness to San Francisco. The distance from the nearest railroad station to the peak is some 40 kilometers, over a rather rough route, though suitable for an automobile. So the astronomers must dwell there all the time, and during the winter this region must lose some of its charms.

We will dwell but little on the great Lick equatorial, one of the most justly famed telescopes of the world. Its focal length is 17.30 meters and its aperture 91 centimeters (36 inches). It may be used for visual observations and adapted for photography by the aid of a correcting lens placed just inside the focus. One of the most remarkable aids used with this instrument, the only rival of which is at the Yerkes Observatory, where it is further perfected, is the moving floor, which may be raised by hydraulic means so that the observer, his assistants, and all which surrounds him may be placed at a suitable elevation.

The great telescope is used for various researches, notably for spectroscopy and the determination of radial velocities. The construction of the spectroscope, known as the Mills spectrograph, was most carefully designed. It has three prisms and an adjusting device which assures the parallelism of the optic axis of the telescope to that

of the collimator, a condition evidently indispensable for the use of all the available light; the tube is sufficiently rigid to allow the realization of this. It is well known that one of the principal difficulties in the accurate measurement of radial velocities results from the changes of temperatures which change the indices of refraction of the prism during the necessarily long exposures and thus produce a false displacement of the spectrum lines. In order to escape this danger the whole dispersive system is surrounded by a thermostat which maintains it at a constant temperature. It consists of a wooden box, lined with thick felt. By means of an electric fan and a fine German-silver wire passing along the sides of the box and traversed by an electric current of moderate intensity the box may be rapidly warmed when the temperature becomes too low; a thermometer, by means of an auxiliary current, stops the warming current when the proper temperature has been regained.

Naturally the great equatorial of this observatory is particularly suited to measures upon double stars; we ourselves were able to separate the two components of the close double δ Equulei (0.3″ apart), and R. G. Aitken, the astronomer in charge of these researches, on nights of good seeing does even better and can separate those as close as 0.14″. He has already published 2,000 new doubles hitherto uncatalogued.

Notwithstanding the superb qualities of this instrument, its angular aperture (about 1 to 19) is too small for use in photographing very faint objects, such as nebulæ and comets, and for this purpose they therefore employ the Crossley reflector, whose aperture is 36½ inches. This instrument has had a somewhat peculiar history and its mounting has been wholly rebuilt during the last few years in the shops of the observatory. As they had especially in view its use in photography, rigidity was considered a most essential quality. In order to follow a star across the meridian without having the telescope strike the pier and thus avoiding the necessity of then reversing the instrument, which would have been very undesirable in the middle of an exposure, they adopted the English form of mounting where the two extremities of the polar axis rest upon separate piers. In order to diminish the moment of inertia of the moving parts, which weigh 6 tons, they gave the polar axis the bizarre eccentric form shown in plate 2; the eccentric portion serves partially as a counterpoise and the radius of gyration is decidedly reduced. The driving sector has a radius of 2.50 meters so that any irregularities due to its movements are much reduced. In order to keep the image of the star being photographed constantly at the same point of the plate it has usually been the custom to move the whole telescope by the means of slow-motion mechanisms; with the Crossley reflector only the plate holder is moved. Two micrometer screws give it the

necessary correcting movements, thus avoiding the useless waste of exertion in the older method. Finally, a very small, convex, hyperbolic mirror, placed near the principal focus, allows them to give to the telescope the Cassegrainian form, increasing its focal length for the study of the brighter stars.

With this instrument, and indeed, with its old form of mounting, the Lick observers were able to obtain a superb series of plates of the nebulæ, which are rivalled only by those obtained during the past year at Mount Wilson. They hope to photograph thus 120,000 nebulæ, possibly many more, and our present catalogues contain only 13,000.

The spiral form is much more general among nebulæ than was formerly supposed, a result which becomes even more interesting since the Crossley reflector has enabled Fath to obtain the spectra of several of them. He found their spectra very remarkable and composed of three distinct types; a continuous spectrum, bright nebular lines, and dark absorption lines. The theory that these nebulæ are very condensed masses of stars is therefore supported by this.

THE YERKES OBSERVATORY.

Less favored than the Lick Observatory by its climate, the Yerkes Observatory is near Chicago; it was dedicated in 1897 in the presence of a gathering of astronomers from the whole world. It owes its inception to the energetic initiative, assisted by the means of a wealthy manufacturer, of Dr. Hale, who was its first director and who proposed to make it a center of the first rank. Its great telescope, with an objective (pl. 3) of 1.02 meters (40 inches), derived much profit in its construction from the one previously built for the Lick Observatory. All perfections possible seem to be combined in this instrument, which, with its moving dome, cost some $170,000. The moving floor is raised by electrical means, the clock rewinds itself, and yet other motors direct the telescope to the desired place—indeed, no convenience has been omitted.

One sees here vividly how American methods of construction differ from ours, how little they concern themselves with customs so rigorously observed elsewhere. Our great instruments always seem to be built according to some former shop rules, very different from the practice in the construction of the machinery of ordinary manufactories. Such is not the case with the great American telescopes; their parts are more massive, less fragile, and have the appearance of the machinery in the ordinary commercial industries. Everything must conduce to regularity of operation rather than to surface refinements. Precision becomes illusory where there is flexure and the strains tend constantly to destroy the perfection of the surfaces and their adjustments.

THE GREAT 40-INCH EQUATORIAL OF THE YERKES OBSERVATORY AT WILLIAMS BAY, WISCONSIN.

DETAIL OF THE EYE-END OF THE 40-INCH, SHOWING THE PLATE HOLDER MOVABLE WITH RESPECT TO THE REST OF THE INSTRUMENT.

Several spectroscopes of one or several prisms may be attached to the telescope; we will mention especially the Rumford spectroheliograph. Hale had especially in view the study of the sun when he founded the Yerkes Observatory. So he had the great refractor furnished with adjuncts analogous to those which he had used in his private observatory at Kenwood for his earlier solar researches. Yet we will find that there is now a tendency everywhere to adopt widely different schemes for this class of researches.

Under the incentive of Prof. Frost, now the director at the Yerkes, progress has, of course, continued. With the 40-inch Burnham made his great catalogue of double stars published in 1906. This includes many new doubles, which European astronomers may not hope to see. In photography Ritchey, the clever constructor and observer now at Mount Wilson, first applied at the Yerkes the idea of moving the plate holder with its plate (pl. 4) in following a star instead of moving the whole telescope. And yet further, by the use of isochromatic plates combined with suitable color screens for eliminating the blue and violet rays for which the objective was not corrected photographically, he succeeded in obtaining remarkable plates of star clusters.

Studies in photometry have been carried on at the same time, and, just as at Meudon, daily photographs are taken of the protuberances of the sun, and also of the strata of calcium and hydrogen over the whole solar atmosphere.

The Yerkes Observatory has other instruments: a telescope of 24 inches constructed there almost entirely by Ritchey; finally, through the generosity of Miss Bruce, there is a photographic telescope of 25 centimeters linear aperture and 1 to 5 angular aperture of large field, which has enabled Barnard to obtain, besides numerous photographs of the comets which are magnificent, plates of large areas of the milky way and to discover through these latter those large, dark, star-free places, commonly called coal sacks, which so perplex the scientist.

FLAGSTAFF OBSERVATORY—MARS AND THE PLANETARY SURFACES.

And now we will pass to a class of work which recently has aroused lively curiosity even outside of scientific circles; this is the study of the surfaces of the planets, undertaken especially since 1894 and in particular very recently at the observatory at Flagstaff by Percival Lowell. Mr. Lowell, a rich amateur astronomer, early conceived a passion for studying the question of the "canals" of Mars and has become an ardent and intelligent advocate of the habitability of this enigmatic planet. The Martians seem almost friends of his, he has become so ardent in describing their exploits. In order to better

observe their deeds and manners Lowell has chosen on the Arizona Plateau a privileged site near the route of the Santa Fe, a short distance from the Grand Canyon of the Colorado River, the marvels of which we could not tell here without departing from the purpose of this article. A dry and desert climate, high altitude, and distance from the smoke of manufactories, all contribute to give beautiful images in their telescopes, and they are indeed so very often.

At Flagstaff they employ chiefly an equatorial of 0.61-meter aperture and 9.45-meters focal length and propose, besides direct visual observations, to obtain photographs as perfect as possible of the great planets. Lowell noted that generally the definition of the telescopic images is vitiated by the undulations in the lower layers of our atmosphere whose wave-lengths are of about the order of magnitude of the diameter of the object glass, although often smaller. With such disturbances it often happens that the bundle of light waves having traversed regions differently agitated produce a general blurring of the image which is not compensated by a smaller diffraction. Lowell therefore thinks it preferable to diaphragm his objective to 0.30 or 0.45 meter. Each of the exposures, which are made in series, receives a bundle of these varying rays which have followed very closely neighboring paths and traversed practically the same atmospheric course. Accordingly the images are very sharp, especially as care is taken to choose the most favorable moments. However, this is not all there is to be said. The form of the diffracted bundle of rays is that of a sugar loaf (conical), so that the diffraction of the image formed of a point is smaller the closer to the summit we cut the cone; or, practically, if we absorb a part of the light by interposing a screen before the plate we will diminish the harmful effect of the diffraction, thus improving the definition of the image. This happens very fortunately, for in the use of isochromatic plates with an ordinary objective corrected for visual observation, we have already stated that it is necessary, in order to obtain a sharp image, to absorb the blue rays by the use of a yellow screen.

Lowell and his assistants, Slipher and Lampland, have thus been able to photograph for the first time the "canals" of Mars, and, indeed, so they think, to discover new ones of recent formation. To continue with the suggestive deductions which have led them to conclude the existence on our neighbor of intelligent beings—indeed, yet more, of consummate agriculturists!—would take us too far, especially since we would then treat with theories which are strongly contested and upon which we must say that very little light has really been cast. They have made other spectroscopic researches, which have led Lowell to affirm the presence of the bands due to water vapor in the red portion of the spectrum of Mars, a fact favorable to the exis-

tence of people on the planet; but here, also, we must note, there are divergencies of opinion, and we must not insist.

The ingenious methods of Lowell have been applied as well to Jupiter and Saturn; they have revealed on the equatorial bands of these two planets curious oblique filaments, a sort of network (reseau) of cells which had already been noted in visual observations, but the interpretation of which has not yet been found.

Whatever we may think of the theoretical and philosophical ideas of which Lowell is the brilliant champion, there is no doubt that his methods present an important advance; in every way his planet photographs are among the best, perhaps the best, which have been made.

MOUNT WILSON OBSERVATORY—SOLAR PHYSICS.

At Mount Wilson we are brought more especially to the study of the sun. The Mount Wilson Solar Observatory was founded in 1904 through the munificence of Mr. Andrew Carnegie and at the request of Dr. Hale, then director at the Yerkes Observatory. Hale was especially interested in finding for solar physics a very elevated station where the atmospheric disturbances and convection currents would be less noticeable; therefore it seemed to be necessary to seek such a place among the mountains of the Pacific coast, which had been shown to be so favorable for astronomical researches. After a detailed inquiry at various places Hale chose Mount Wilson, a few hours' ride from Pasadena, not far from Los Angeles, a peak of 1,800 meters altitude and crowned with pines; he had transported there a portion of the instruments which he had used at the Yerkes, taking with him also several of his assistants.

At the foot of the mountain in the village of Pasadena are situated the offices for measurements and calculations. Here, as everywhere in America, there is a personnel exclusively feminine, which is an advantage where, initiative being secondary, care and delicacy are required. Finally, in order to reap results from the greatest possible number of plates, a stereo-comparator by Zeiss is used. This is a German device, allowing the exact superposition and the changing at will in the field of vision of two slightly different plates of the same region; the smallest divergencies, the smallest changes, are then easily noted.

We find here also an admirably organized workshop provided with all American mechanical resources, which means that they do here with mechanical means many things that we still do by hand, resulting in a great saving of time. Finally—and this is a thing of capital importance—these machines allow the working of pieces of very great dimensions which could never be executed in the shops of the best French constructors of astronomical instruments.

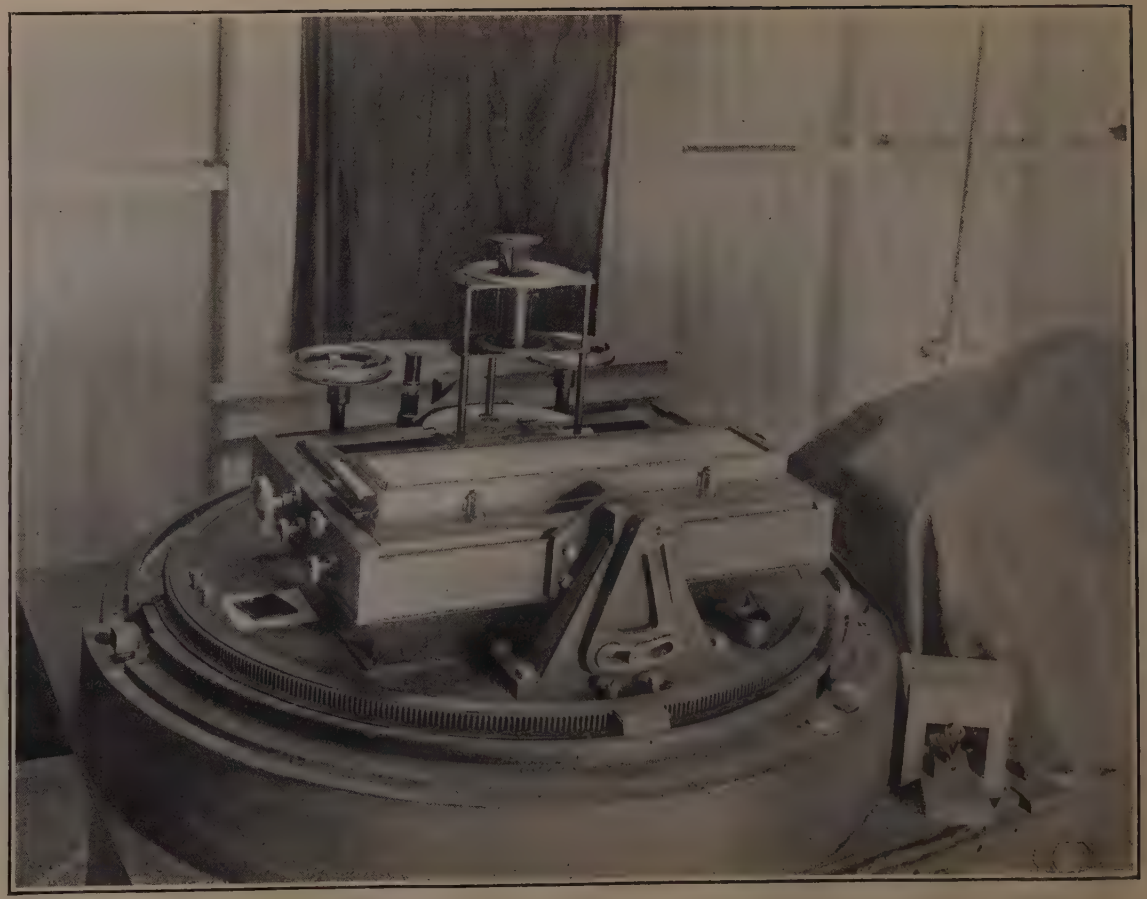
As to the laboratories proper at Pasadena, they also include all that is necessary for physical and spectroscopic researches, which in the minds of the founders should be the indispensable complement of astronomical investigations. If in the laboratory, by known means, the phenomena observed in the stars are reproduced, then, indeed, the presumption is tenable that the phenomena take place in the stars just as they do in our experiment. The proof is truly not rigorous, and the conditions which prevail in the celestial objects are more or less difficult to realize, and may at times result in unexpected consequences. Nevertheless, it is the only method available in astrophysics for attaining the truth, and we must leave to the future the task of definite corroboration. We should add that this idea has become very general, and that all astrophysical observatories have more or less complete laboratories.

Since its construction the establishment at Mount Wilson has been open to astronomers of all nations who have wished to work or study there. And so we had the pleasure of meeting our colleague, M. H. Chretien, of the Observatory of Nice, who had been studying there some eight months. So, also, W. H. Julius was enabled to study in application to the sun his well-known theory of anomalous dispersion set forth in this review in 1903. With this theory he explains a great many phenomena, principally those of the chromosphere and prominences by reason of the curvilinear paths of the light rays in the solar atmosphere. Kapteyn, also from Holland, has come to Mount Wilson for the purpose of continuing his researches upon the absorption of light in celestial space. The differences which he has noted between the visual and the photographic magnitudes of the stars, which become larger the greater the distances of the stars, may be easily explained by the absorption of the light by some cosmic medium.

We have considered the general organization of this observatory; let us now discuss the instruments. The first one put into service was the Snow telescope (pl. 5), which does not differ materially as a whole from that used at Meudon for the study of the solar atmosphere. It consists of a two-mirror coelostat which sends the solar beam horizontally to a great spectrograph and a spectroheliograph. The latter, which is of moderate dispersion, serves to take plates of the sun in monochromatic light several times a day. With it was explored the mean layer of chromospheric hydrogen, in which are seen at times, besides the more important filaments of the upper stratum, isolated later at Meudon, the peculiar more or less vortical movements that bring to mind the classic experiment of the magnetic spectrum.

The instrument next in order to the "Snow" is the tower telescope, which is designed on a totally different plan. In order to

GENERAL VIEW OF THE SNOW TELESCOPE AT MOUNT WILSON, CALIFORNIA.



SLIT AND PHOTOGRAPHIC PLATE HOLDER OF THE SPECTROGRAPH OF THE TOWER TELESCOPE OF MOUNT WILSON.

avoid the irregular refractions produced in the lower air by the heated ground, it occurred to Dr. Hale to place the coelostat upon a tower some 20 meters high, sending the rays vertically downward through a lens of 30 centimeters diameter and 18 meters focal length. The solar image is formed about 1.50 meters above the ground upon the slit of a spectroscope (pl. 6). The light beam then descends into a well 9 meters deep, traverses the dispersive system, which may be rotated about a vertical axis, and the essential part of which is either a Rowland 4-inch grating or a Michelsson 8-inch grating, at will, and finally returns to the level of the ground to the photographic plate. There is yet another spectroscope with a prism, a companion to the last one, which is of great dispersion and mounted as a spectroheliograph. This gives a monochromatic image of a portion of the sun's disk, and either this or the one preceding may be employed at will.

It was with the grating spectroscope of the tower telescope that Hale discovered the magnetic field in sun spots, one of the most beautiful discoveries relating to the sun in recent times. The agitated appearance of the hydrogen flocculi about the spots suggested an investigation as to whether the Zeeman effect might not be produced by them. The hypothesis that the spots have electrically charged matter in rotation indicated the possibility of the existence of such a phenomenon. Indeed, the spectrum of the spots contains a great number of enlarged and reversed lines, an appearance which would be produced by a smaller or greater degree of doubling. Therefore Hale placed before the slit of his spectrograph a Fresnel rhomb and a nicol serving the following purpose: The former transforms the circular polarized light of the Zeeman doublets into plane polarized pairs, and the second, according to its orientation, extinguishes one or the other of the latter components. The experiment confirmed Dr. Hale's theory. The rotation of the nicol 90° caused the disappearance of the right or left line from its original position, while, the telluric lines remained unchanged. Later it was found that this curious phenomenon existed in all sun spots to a degree varying with their size, and that the magnetic field seems to diminish greatly with the height of the vapor above the photosphere, and later yet other peculiarities were found which we can not think of describing here. A vast field thus seems open for astrophysicists, and the astronomers of Mount Wilson will certainly not leave it unexplored.

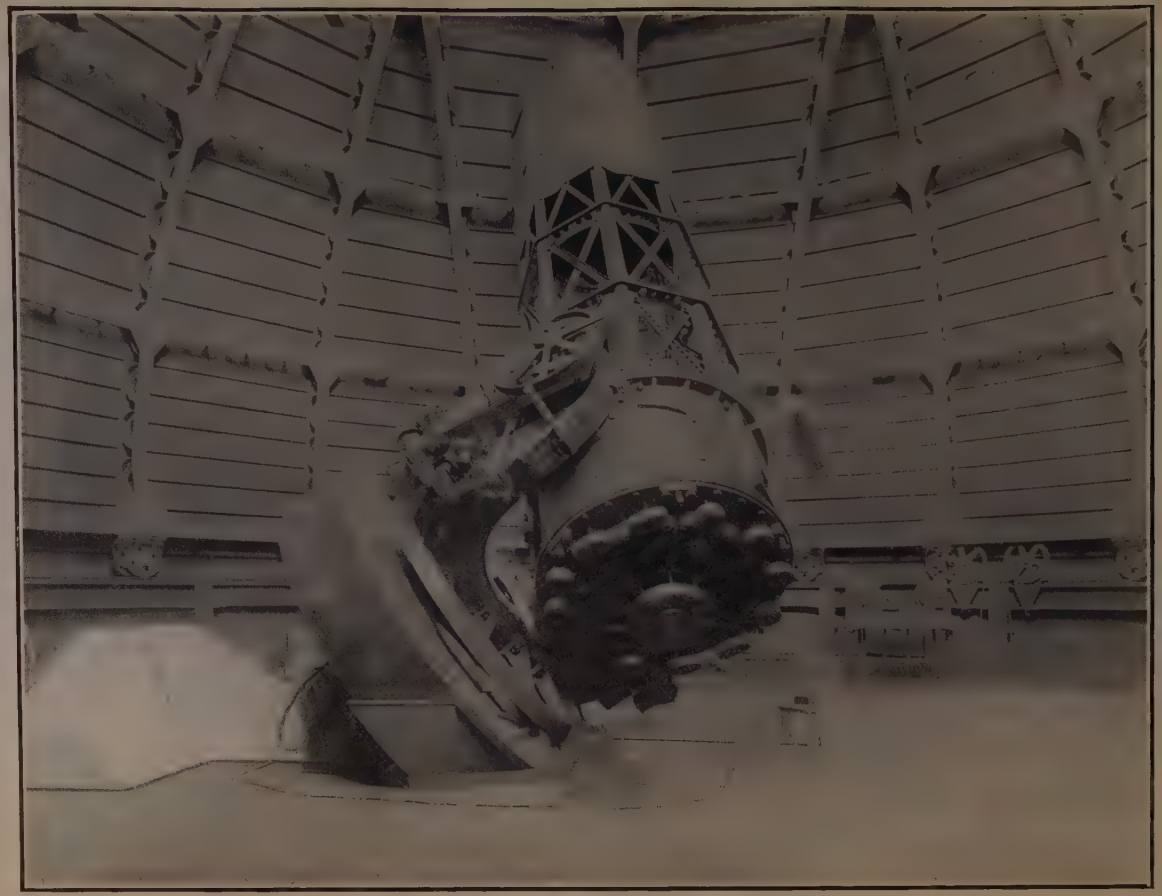
In the realm of pure astronomy the Mount Wilson Observatory possesses an instrument which in power is not surpassed by any other in the whole world—the telescope of 1.52 meters (60 inches) aperture, constructed under the direction of Ritchey, and in use since December, 1908. Its mounting is interesting. The telescope tube, which is of openwork construction, is carried in a forklike

extension of the polar axis. Further, in order to lighten the great weight of the moving portions, it rests at its lower part in a bath of mercury; a large cylinder in the form of a mill wheel, and which may be seen there, plays the part of a float. In all details the designers have profited by the experience acquired elsewhere.

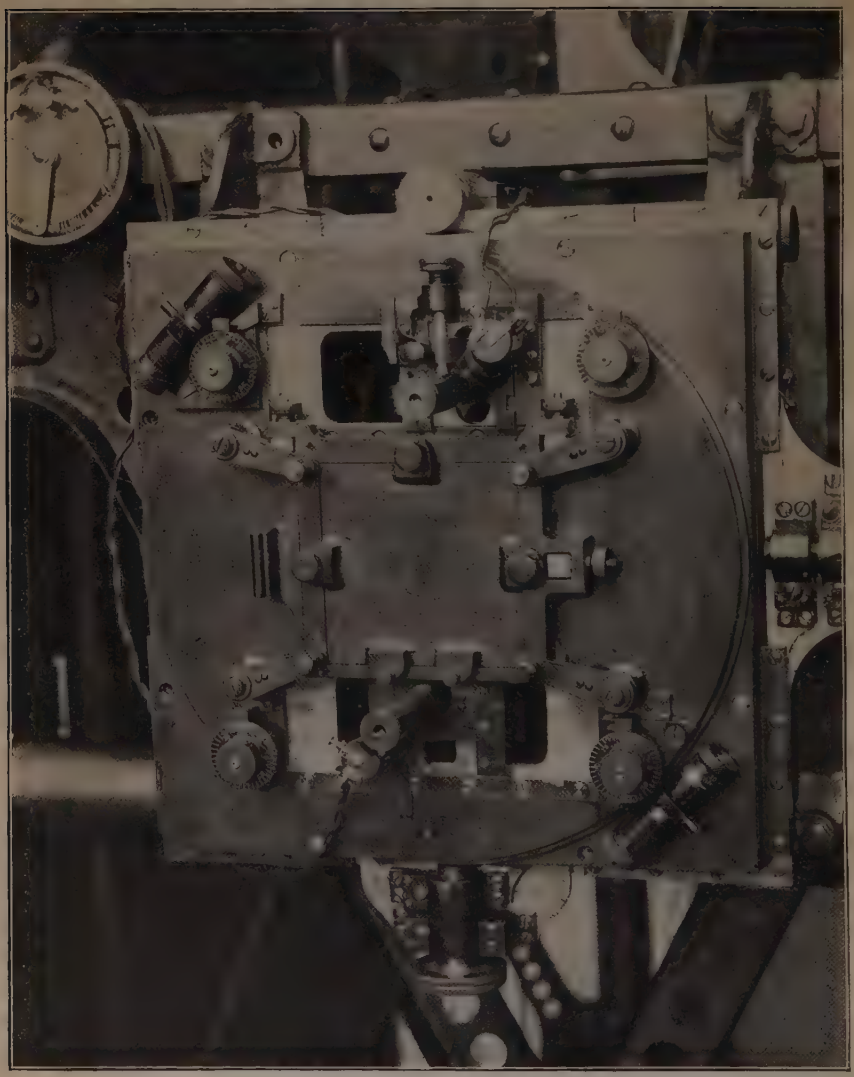
In order to take advantage in every possible way of the light at their disposal various combinations of auxiliary mirrors may be used to give an instrument of various equivalent focal lengths. For instance, the telescope, with its great parabolic mirror alone, has a focal length of 7.6 meters and an angular aperture of 1 to 5. In this form it is adapted for very faint nebulae. In conjunction with a small hyperbolic mirror placed near the principal focus it forms an instrument similar to the Crossley reflector of the Lick Observatory. It has a focal length of 30.60 meters, and at the same time, and this is very remarkable, the images are very greatly improved from certain aberrations. Other arrangements allow foci of 21.40 and, indeed, of 45.50 meters. In the last case, especially useful in the study of the brighter stars, the light beam is sent down through the polar axis—which is hollow—and from there it passes into a subterranean chamber under the pier, where it may be analyzed by means of a fixed spectrograph, free from variations of temperature. We ought to say that in the mind of Ritchey even a focal length of 45 meters is not enough for his work on the moon. He proposes by more or less complicated reflections of the beam of light to photograph our satellite at a focal distance of 150 meters!

Ritchey's method of work deserves description. As at the Lick Observatory, the photographic plate carrier is provided with two micrometer screws at right angles to each other for producing the motions of the plate necessary for "following." It may also be turned in its own plane. By means of two different eyepieces attached to the plate carrier two stars may be seen; the first, which is kept constantly in view, is the guiding star, properly speaking; the second serves to correct the differential effects of refraction which would result in a rotation of the field. From time to time it is noted whether the star in the latter has left its cross wire, and a slight rotation of the plate holder suffices to bring it back to its place. Nor is that all; the focal length of the telescope may change during the course of an exposure lasting some 8 or 12 hours and continued during several nights. This is corrected every half hour by the knife-blade method of Foucault, susceptible of the precision of one-fortieth of a millimeter. For accomplishing this it is, of course, necessary to remove the plate, but a system of stops allows him to put it back into its proper position again.

Ritchey, helped by an incomparable sky, has obtained plates which prove that such refinements are not illusory. His nebulae, of the



THE 60-INCH TELESCOPE AT MOUNT WILSON.



DETAILS OF THE EYE-END AND PLATE HOLDER OF THE 60-INCH TELESCOPE AT MOUNT WILSON.

greatest beauty, show details of structure of wonderful delicacy. Perhaps the most curious of these details are the dark streaks which are apparent, more often than on the Lick plates, between the spirals of a great number of the nebulae. The 60-inch telescope has been in service but a short time, and we feel that there is no danger in predicting that in the near future it will justify by new feats all the hopes which have been placed upon it.

But the founders of Mount Wilson wish to build yet greater instruments. A mirror of 2.54 meters diameter, which we had the opportunity of seeing, is in the process of construction in the workshop at Pasadena. Meanwhile a new tower telescope, nearly 50 meters (150 feet) tall is nearly completed. This latter structure, analogous to the one we have already described, will give at the level of the ground a solar image 40 centimeters in diameter; it will be completed below by a well 24 meters deep containing the spectroscopes. Imagine what may be done with such apparatus! Nevertheless, it is to be feared that the improvement of the image anticipated by Hale may be compromised by the vibrations of the coelostat tower despite all the precautions to diminish them.

We can not leave Mount Wilson without mentioning an extremely interesting work which is also going on there; one which has already accomplished results of the first rank. We refer to the observatory of the Smithsonian Institution which, under the direction of Mr. Abbot, proposes to continue and extend the work of Langley upon solar radiation. We can say that the results of these researches represent our most accurate knowledge upon many of the most important details of solar physics; notably, the distribution of energy in the solar spectrum, the absorption in the atmosphere, and the solar constant of radiation.

CONCLUSION.

We have passed in review all the principal American observatories. The more common American traits, you have without doubt remarked, are the extreme perfection of mechanical means, an ever-watchful ingeniousness and the absence of all spirit of routine in their constructions. We are speaking of the United States, where everything in the daily life tends to develop practical ideas; and an almost feverish activity turned unceasingly toward advancement is noticeable in every profession. Meanwhile, we should not forget that all these superb observatories, all these powerful instruments, owe their existence to the enlightened and regal generosity of the wealthy American men of industry. It is curious to note that these men whose energy, at times hard hearted, has brought them success, seem more attracted toward science than to those who have failed

in the daily struggle for existence; in Europe, conversely, and more especially in France than elsewhere, the few possessors of great fortunes tend to leave a reputation, perhaps less durable in the end, of philanthropy. Their gifts, at least to some extent, might be more judiciously distributed, in the interest of the moral prestige of our country, to aid scientific institutions which struggle so painfully to maintain a glorious past.

What fortunes, in our annual budget of some 4,000,000,000 francs, go every year to the State to be frittered away without profit to anyone which, if given to one of our great institutions, would revivify their founder's prestige and perhaps yet accomplish great things in the future.

THE FUTURE HABITABILITY OF THE EARTH.[1]

By Thomas Chrowder Chamberlin,
Of the University of Chicago.

Ever since the human race came to have a virile desire for intelligence it has tried to peer into the future that it might satisfy its curiosity and guide itself by foresight. Now and then it has tried to prolong its vision beyond the immediate future that it might forecast the destiny of the race and the fate of the earth on which it dwells. In all these endeavors the depth of its penetration into the unknown before it, has been closely measured by the depth of its vision into the history behind it, and both the look before and the look behind have been close akin to the depth of its vision into the things about it. The light of the present and the lamp of the past have been its guides in the forecast. Beyond question this is the true method, and doubtless it will always remain the true method, for only as the race sees far into the past, and probes deeply and widely into the present, has it any firm basis for a sure prophecy of the future.

The race did not fail to note even in its early days that the existing forms come into existence, live their day, and pass away. Why not then the race and the earth on which it dwells? While it was felt that this might not be true of the ultimate entities, it seemed clearly to be the order of things with the tangible forms. And so it will doubtless continue to be as the race grows into its fuller intellectual maturity and the horizon of its vision is enlarged, for there will no doubt remain the conviction that there has been a beginning of the current order of things and a like conviction that there will be an end. The increased breadth of vision that will come from research will only serve to bring into view still greater multitudes of organisms that have come into form, endured for a time, and passed away. And so any future change in the mode of building up the forecast

[1] This paper is essentially the same in substance as the presidential address before the American Association for the Advancement of Science delivered at Boston Dec. 27, 1909, but it has been freely revised and given a briefer title for publication in the Smithsonian Report.—T. C. Chamberlin.

is not likely to be guided by a new fundamental method, but merely by an increased measure of breadth and depth of insight.

Some of the special features that have entered into former prophecies will quite surely disappear and new ones will no doubt be added. The forecasts of prescientific times often made the doom of the earth hinge on some lapse in the conduct of man; made a physical disaster serve as a moral punishment. But with a truer insight into the basis of moral law and the place of man in nature this anthropic view will no doubt give place to a more consistent conception of sequences in the moral and the physical worlds.

In the earlier days of the race the backward look was short, and in fitting accord with this the origin of the race and of the earth was put only a few thousand years before our times. In strict consonance with this the forward look seemed to disclose an end but little ahead. In much the same tenor also the beginning was made chaotic and the end cataclysmic.

The dawn of the earth sciences was followed by a new forecast, and as the sciences grew this forecast was repeatedly enlarged, revised and recast. It was learned that the history of the earth stretches back not merely for thousands, but for millions and tens of millions of years; that the ongoings of the earth are actuated by energies too great to be seriously swerved from their orderly course or brought to an end by the acts of those who dwell upon it; that the march of earth history has a mighty tread whose moving force feels no serious influence from the merits or the lapses of even our potent race.

The trend of prophetic thought under the inspiration of science in the last century invites a closer review. The ground of forecast lay mainly in the views of the origin of the earth then current, in the course of the earth's past history, and in the trend of those agencies that control the conditions of life. The solar system was then thought to have sprung from a gaseous nebula, and the earth, as a member of the system, was assigned a place in the gaseous evolution. It was itself pictured as a fiery gaseous globe. We need not here turn aside to review the special phases of the dominant hypothesis or of the quasi-gaseous meteoritic hypothesis, or pause to pay honor to their great authors, for the sole feature that entered potentially into the shaping of the future of the earth was the gaseo-molten state assigned the globe at its genetic stage, and in this feature all varieties of these hypotheses essentially concurred. A crude alternative view was, indeed, offered in what was little more than the rough suggestion that the earth might have grown up by the infall of small sporadic bodies, but this did not gain the assent of students of celestial dynamics familiar with all that is implied by the symmetry of the system. On the contrary, it was held that the rotations of the planets

implied a partition from a rotating mass, and so a genesis from a gaseous or quasi-gaseous body was almost universally accepted as by compulsion.

Starting as a gaseous globe, an early passage into a molten sphere wrapped in a hot vaporous atmosphere was logically assigned the earth. The atmosphere was made vast to contain all the water of the globe and the volatile matter that the heated conditions were presumed to have generated. At a later stage a crust was assigned to the cooling globe, and the waters, condensing on this, gave the infant earth the swaddling bands of a universal ocean. On further cooling, shrinkage and deformation were supposed to follow, the waters to be gathered into basins, the land to appear, and the formation of earth strata to begin.

It is important to note that the main agency in this hypothetical history was the loss of heat, and so, with logical consistency, loss of heat was made to lie at the bottom of the great events of the earth's history down to the present time, and, in framing a forecast of the future, loss of heat was made the chief cause of the earth's prospective doom as a habitable planet. The whole history was interpreted as a stupendous declension. From a plethora of heat at the outset loss followed loss till our semiglacial stage has come, and, by prophecy, loss is to follow loss in the future till the final winter shall come. Starting with a plethora of air and water swaddling the earth, loss followed loss till our emaciated stage has been reached, and loss is to follow loss till drought shall join frigidity in marking the final state and the end of all life. The details of this inherited picture were not wanting. As the body of the earth cooled and shrank, the waters were permitted to enter it and by union with its substance lose their fluid state. In like manner the air, entering the earth and uniting with it little by little, depleted the smothering atmosphere, lessened its oppressive weight, tempered its noxious nature until it was compatible with low life, and later with higher life, and at length brought it down to the present state. Projected into the future, the forecast tells of further depletion, with the pauperization and at length the extinction of life.

The shrinking of the oceans more and more into the deep basins, the absorption of the waters into the body of the earth, and the progressive cooling and emaciation of the air were logically supposed to join in progressively reducing the vapors that rose from the waters. At first, hypothetically, a deep warm mantle of cloud clothed the whole earth, and this shroud was thought to persist halfway down the geologic ages, giving sultry, lowering climates in all latitudes. At length, however, this mantle was pictured as giving place to rifted clouds and clearer skies, and still later to mild aridities, to be followed in turn by desert stages, and these, growing apace, led on to

the saharas of to-day, which are even now held by this school of thought to be creeping out persistently on the once fertile lands. Thus is reached our own time, when heat and air and moisture are all running low, putatively, and are thus foreshadowing the predestined end in the not distant future.

Life history is thus made but an episode in the midst of this great declension from the too hot and the too much to the too cold and too little. The life period merely spans a lapse on the slope from excess to emaciation.

The logic of all this is plausible, the premises once granted. Starting with the hypothetical postulates, the conclusions seem almost necessarily to follow. The details, indeed, may not all have been as mapped, but, the premises granted, the general course of progress was scarcely less than inevitable. Sources of delay and causes of deviation might, indeed, have been found in means that furnished a greater or less supply of air, or water, or heat to offset the waste, but the presumption of a downward trend carrying the whole along with it is not easily escaped.

In point of fact, the general conception of a progressive declension dominated the geologic thought of the last century. Not only did it dominate the forecasts, but it gave direction to the interpretations of the geologic record, and in no small degree it unconsciously influenced the observations of geologic phenomena, and this domination continued well down to the close of the last century and is far from obsolete to-day.

But logical and plausible as is this inherited picture of the history of the earth, it was hung on the particular hypothesis of the genesis of the earth that was then currently accepted. However logical, its logical strength was only that of the hypothesis on which it was hung. I say logical strength advisedly, for outside the logic of the concept there was always the appeal to the record. This appeal was made and was thought to be in the main confirmatory. The strata of high latitudes were found to contain relics of life of subtropical types, and this was found true not only of the very early ages, but of ages well down toward recent times. Figs and magnolias grew in Greenland as late as the Tertiary period. So impressive was the presence of subtropical plants in strata almost under the very edge of the Greenland ice cap, that it gave deep hold to the logical inferences with which it seemed to be so strikingly in consonance. Phenomena not so consonant with the concept were easily overlooked or lightly passed by, as is our wont when too much impressed by what must be. It is, however, a merit of modern science that it prompts us to put to the front that which is and to relegate that which merely must be to a secondary category. And so all along during the past century the inconsonant elements of the record were gathered as well as the

consonant. Most of the former were of the unobtrusive sort and awakened little questioning, but some of the facts were startling, some were indeed apparently quite incredible, and as a matter of fact were long subject to the suspicion of being the offspring of illusion or inaccuracy. Only very slowly under the influence of repeated confirmation did they gain credence. The gathering of this inconsonant data gradually weakened the hold of the inherited concept and prepared the way for a reconsideration.

Meanwhile, in the progress of physics, a serious source of doubt had arisen respecting the tenability of the gaseous basis of the concept. The older hypotheses of the origin of the earth were framed before the kinetic theory of gases came into currency. After the kinetic theory had been accepted, it was urged, notably by Johnstone Stoney, that the velocities of some of the molecules of the outer air must be such as to give rise to their escape, and thus to put a limit to the amount of atmosphere which the planet could hold. When a test of this type was brought to bear on the vast hot atmosphere assigned the primitive earth, it gave rise to doubt as to the physical tenability of the concept.

Weakness also arose in another quarter. One of the main props of the gaseous and quasi-gaseous hypotheses of the earth's origin, was the conclusion that a condensation from any other dispersed state than the gaseous or quasi-gaseous would lead to revolutions and rotations in directions opposite to those actually possessed by most of the planets and satellites. A closer examination of this deduction under the stimulus of the doubt that had arisen from the kinetic test showed weakness here also, and even a reversal of probabilities, for it appeared that a slow ingathering of matter from a scattered disk-like orbital state would give revolutions and rotations even more consonant with the actual facts than would centrifugal evolution for a gaseous globe, as previously postulated.

Thus, toward the close of the last century, there arose from different quarters cogent reasons for a restudy of the whole subject. Further scrutiny added new sources of doubt, and in the end the tenability of all the gaseous and quasi-gaseous hypotheses was challenged and a new genus of hypotheses, based on orbital dynamics, in contradistinction from gaseous dynamics, was offered instead.

It is not appropriate for me to say that this challenge was successfully supported, or that the older concepts of the earth's origin are to be laid on the shelf. As an advocate of the method of multiple working hypotheses, it belongs to me rather to beg of you to keep in use—so far as you find in them any working quality—all hypotheses that yield any wholesome stimulus to inquiry.

Much less would it be appropriate for me to affirm that any form of the newer concepts is entitled to take the place of the older in

your complete confidence. The final adjudication of a genetic hypothesis of such a remote and complex an event as the birth of the earth and the solar system can only come of protracted scrutiny by means of diverse forms of searching analyses and trenchant logic, and of long and patient trial in testing the hypothesis by the multitudinous phenomena constantly coming to light from the earth, the solar system, and the heavens beyond.

It is sufficient warrant for the present review, however, that not a few incisive students of celestial dynamics have been led to seriously reconsider the foundations of the hypotheses of earth genesis, and that not a few geologists have been led to scrutinize with renewed care the inferences and interpretations that have been hung upon past theories of earth genesis. Whatever may be your personal leanings, you will no doubt agree that it seems less permissible now to hang prophesies of the future upon challenged hypotheses of genesis than it might once have been, when a certain hypothesis or a certain class of hypotheses received the almost universal assent of those who seemed then best qualified to hold opinions respecting them.

It does not seem to be going too far to say that whereas we formerly seemed shut up to hypotheses of genesis that assigned the earth a gaseo-molten state at the start, it now seems to some of us at least that the earth may have inherited a quite different state from a slow growth by the ingathering of small bodies of a planetesimal nature. If views that are thus fundamentally diverse are permissible, and if these give rise to a wide range of alternative working conceptions, we are freed from some of the constraints of interpretation that have hampered our reading of past history and colored our outlook upon the future. Let us, therefore, pass in brief review the states assigned the early earth by the newer conception of earth genesis that we may gain a concrete impression of the lines of interpretation it opens to us, and then let us turn to the critical phenomena of the actual record as the more solid basis for a forecast of the planet's future.

Quite in contrast with the older pictures of the primitive earth, the planetesimal hypothesis—and this is entitled to be taken as the type of theories based on concentration from a scattered orbital state—postulates a solid earth growing up slowly by accessions and coming to be clothed gradually with an atmosphere and hydrosphere. The earth, the air, and the water are made to grow up together from smaller to larger volumes without necessarily attaining a very high temperature. The sources that at the first had furnished the body of the ocean and the air, though they fell off as time went on, still continued to serve as means of replenishment, and to act as an offset to the familiar agencies of loss far down into the later ages, if indeed

they are not still in function in some degree. And so, far from assigning a vast atmospheric and oceanic supply at the start and bringing to bear on this a progressive depletion all down the ages, the newer view starts with a much more limited supply and rests on means of continued feeding as time goes on, and makes this feeding run hand in hand with the secular losses in more or less equal balance after the initial stages of growth were over.

The question of the future, under this view, is not how long will the remnant of the original supply last, but rather, how long will the past and present degree of equilibrium between loss and gain remain effective? The equilibrium is held to be oscillatory but the limits of oscillation fall within the limits of the conditions of life. The specific question of the future, so far as our race is concerned, is, how long will such a degree of equilibrium as has prevailed in the past continue to preserve the critical conditions prerequisite to life?

The question in this aspect turns us quite away from any serious concern respecting original abundance and centers attention on the geologic record itself as an index of past competencies. In particular it turns attention on the agencies of equilibrium to see if there are signs of any fatal weakening of competency. Are the chief agencies which have controlled life conditions for tens of millions of years still in good working order and likely to continue effective for a long era yet to come, or do they show clear signs of declining power portending an early failure?

Let us enter a little closer into a study of the specific factors on which life depends, though we may not go far.

The ancient fear that the end of the earth will come by cataclysm is not yet obsolete nor is it theoretically quite impossible, but violent agencies are among the least to be feared. Volcanic or seismic convulsions may be imagined to put life in jeopardy as indeed they often actually do locally, but they really offer no serious menace to life in general, and they do not appear ever to have done so in the known ages. The spectacular destructiveness of these boisterous agencies deeply impresses the emotions, but they contribute but an infinitesimal fraction to a sober computation of the effective sources of loss of world life. The real peril, if peril there be to the whole world life, lies in the deadly unbalancing of agencies of the quiet sort.

The conditions essential to the maintenance of the habitability of the earth are many, but the more critical factors either lie in the atmosphere itself or are intimately associated with it. The fact of keenest interest is the narrowness of range within which the critical conditions are confined. Any of the constituents of the atmosphere or all of them might easily, it would seem, be too scant or too abundant to be consistent with life as now organized. In a

peculiar sense it would seem that this might be true of carbon dioxide, for it is one of the least of the constituents and is one of the most active chemically, and has come thereby to be preeminently the critical constituent of the atmosphere. Some small proportion of this element is altogether necessary to plant life, and so to animal life dependent on plant life, while a large proportion of carbon dioxide would be fatal to air-breathing animals. If the three or four hundredths of one per cent now present in the air were lost all life would go with it; if it were increased to a few per cent the higher life would be suppressed or radically changed. And yet the theoretical sources of supply are abundant enough for imaginable disaster of the one order, while the agencies of depletion have theoretical efficiency enough for imaginable disaster of the other order. But neither Scylla nor Charybdis has swallowed up the living kingdom. There seems little escape from the conclusion that ever since the birth of air-breathing life, some 30,000,000 or 40,000,000 years ago, let us say, the interplay of the opposing agencies of supply and depletion has been so balanced that neither fatal excess nor fatal deficiency has been permitted to cut short the history of the higher life.

The dangers of excess or of deficiency of the other constituents of the air are indeed less narrow as named in percentages, but they are scarcely less real in theoretical possibilities.

The well-being of life is also hemmed in between a suitable proportion of moisture, dependent on an adequate water surface, on the one hand and a diluvial excess on the other. Universal deluges and universal deserts would alike be disastrous to our race. A few thousand feet more of water depth or a few thousand feet less would alike exclude our race and seriously restrict the class of life to which we belong.

In even a more serious way the habitability of the earth is conditioned on a range of mean temperature of some such measure as 100° C, roundly speaking. The higher life is in fact confined to a narrower range. This is scarcely 5 per cent of the range of natural temperatures on the earth and a still smaller per cent of the range in the heavens. A few miles above us and a few miles below us fatal temperatures prevail. It is deeply significant that the thermal states of the narrow zone of life on the face of the earth should have been kept within so close a range as to permit millions of species to follow one another in forming the great genealogical lines which lead continuously up from the primitive types to the present ones without breakage of continuity in all the ages, while the prevailing temperatures a few miles below them and a few miles above them, as well as in space generally, would have been fatal. While this constant and necessary supply of heat has come from the sun, the control of tem-

perature at the surface of the earth seems none the less to be intimately dependent on the atmosphere and to constitute a further index of its critical character.

To appreciate the full significance of so effective a control of life conditions poised thus between excess and deficiency, with the danger line close on either hand, while the possibilities were so free and so wide, there is need for some measure of the time through which the delicate poise has been held. But there are now no means for any close measure of the geologic ages; there are merely rough estimates which give the order of magnitude. Life was far advanced in its career when first a readable record was made; but yet, since that record began, 100,000 feet of sediments at least—not to choose the largest estimates—have been laid down by the slow methods of wash from the land and lodgment in the basins. The number of years this implies has been placed variously from 50,000,000 to 100,000,000, with, indeed, higher figures as well as lower. Merely to roughly scale the order of magnitude without pretense of accuracy, let us take the midway figure of 75,000,000 years as representative. Let this be divided into 15 periods which may be made to average 5,000,000 years each, and these will roughly represent the technical "periods" of geologists. By this rough scale we may space out such of the great events as we need now to review. These events are such as tell us of the states of the atmosphere and of the temperatures that prevailed on the surface of the earth at a sufficient number of the periods to show the general tenor of past history in matters critical to life.

As an index of arid conditions we naturally turn to the products of evaporation. In interpreting there is need to note that there may be small excesses of evaporation over precipitation without giving rise to appreciable deposits of evaporation products, for in almost all cases the area that collects rainfall is larger than the portion of the basin that actually holds it, because some point on the rim of the basin is almost inevitably lower than the rest, and this lowest point permits the accumulating waters to drain off to its level, so that it is only the smaller water surface thus left that is exposed to continuous evaporation and takes part in the concentration of dissolved substances into beds of solid salt and gypsum. It is therefore fairly safe to infer a decidedly arid climate when beds of salt and gypsum are found spread over wide areas, especially if these also bear appropriate physical characteristics and if the adjacent deposits are totally free of life or carry only fossils of such types of life as can tolerate a high degree of salinity, or such as show signs of depauperization by the adverse conditions of aridity and salinity.

Now, extensive deposits of salt and gypsum are found in the Salt Range of India in strata of the Cambrian period, the earliest of the 15 periods that make up our rough scale of 75,000,000 years. Because

these salt-bearing strata lie so near the beginning of the readable record of life they are singularly instructive, for they give an insight into climatic conditions well back toward the primitive state of things. They challenge at once the view that in these early ages the earth was swaddled in a dense vaporous atmosphere from pole to pole, for under such a vaporous mantle a broad desert tract in India seems scarcely credible.

If we come forward in time two periods to the deposits of Silurian times, we find great sheets of salt and gypsum underlying the St. Lawrence Basin in New York and westward, with a spread of many thousand square miles. In some parts of the accompanying beds there is complete barrenness of life; in some other parts the life seems to be pauperized, or to be only a remnant selected by hard conditions from an ampler fauna. The physical characters of the deposits of sand, silt, and lime seem to add strength to the interpretation that this great area where now lies a part of our great lake system was affected in Silurian times by an aridity that gave it scarcely less than a desert aspect. These signal facts join with those of the Salt Range of India in challenging the former picture of a universal envelope of vapor and cloud in all those early times, while it is in keeping with such a diversity of climate as has prevailed in later ages.

In the next period there are formations that have been interpreted as implying desert conditions, but the evidence is less strong; and we pass on to certain stages of the sub-Carboniferous period next following, wherein beds of salt and gypsum are found in Montana, Michigan, Nova Scotia, and Australia, thus implying wide but not general arid conditions.

Passing on to the Permian and Triassic periods, near the middle of the geologic series, beds of salt and gypsum are found to be phenomenally prevalent on both the eastern and western continents, with a surprising range in latitude. The relative paucity as well as the peculiar characteristics of the life of those times seems equally to imply vicissitudes of climate in which aridity was a dominant element. There seems no tenable way to interpret these remarkable facts of the middle periods except by assuming an even greater prevalence and intensity of aridity than obtains at the present day.

So, too, at certain times in later periods, but at certain times only, the stratigraphic record implies atmospheres as arid as those of to-day; not everywhere, indeed, but much as now, in particular areas and at certain horizons.

These significant facts make up one group of phenomena; but there is another side to the picture.

If the record be searched for facts of opposite import, they will come easily to hand. Indeed, as already noted, they seemed to the

early geologists to be the more intrusive. In the early part of the record it seems peculiarly easy to find convincing evidences of stages marked by prevailing humidity, by great uniformity of climate, and by conditions congenial to subtropical life ranging through wide stretches of latitude. If we continued to center attention on these alone, the old view would now, as heretofore, seem to be sustained. But these evidences do not abound at all horizons, and the view is selective. Between these horizons lie the strata that bear evidences of marked aridity as well as those that bear the still more impressive evidences of low temperatures to which we shall turn in a moment.

Combining the two sets of facts of diverse import, we seem forced to recognize that from the earliest known stages of distinct life record there have been times and places of pronounced aridity much as now, and sometimes even more intense, while at other times and places intervening between these, humidity has prevailed.

This picture of alternations grows in vividness and strength if we turn from states of atmospheric moisture to states of temperature. The body of scientific men have rarely been more hesitant in accepting any interpretation of terrestrial phenomena than that of the glacial invasion of the lowlands of Europe and America in mid-latitudes when that view was first advanced by Louis Agassiz. In the face of the then prevalent view of general warmth as the dominant characteristic of all the earlier ages, it seemed beyond belief that great sheets of ice could have crept over large areas of the habitable part of Europe and America even in the geologic stage just preceding our own. The acceptance of this view was, however, made somewhat less difficult by the belief, also then prevalent, that the earth had greatly cooled down in the progress of the ages, and that concurrent with this the atmosphere had been much depleted by the formation of oxides, carbonates, coal, and carbonaceous matter, and that the ocean had been reduced by hydration and by physical penetration into the earth. By the combined influence of these it was easier to believe that a stage had been reached that made possible an epoch of exceptionally depressed temperature attended by glaciation. These special pleadings were in eminent harmony with the inherited view of a great thermal declension as the master fact of geologic history, and under this influence the ice age came to be generally regarded as but the first episode of a succession of secular winters upon which the earth was entering, a series destined to lead on to the total refrigeration of the earth. This presumption was furthermore abetted by the theory of a cooling sun. The cooling and depleting processes were naturally regarded as inevitably progressive, and so the final doom of the earth seemed clearly foreshadowed in the near future, geologically speaking.

But opinion had scarcely more than settled down to this interpretation, with a reluctant acceptance of the glacial evidence, when the geologists of Australia, of India, and of South Africa, severally and independently, and later those of South America, brought evidences of still earlier glaciation prevalent over wide areas in those low latitudes. The marks of glaciation were altogether typical and were traced up to and even somewhat beyond the tropical circles from both sides and in the same quarter of the globe, from Australia on the south and from India on the north. Moreover, all these cogent evidences were reported for strata referred to the Permian or Permo-Carboniferous times, i. e., from about the middle of our scale of technical time periods. For a score of years the body of geologists who could not personally inspect the evidence doubted its interpretation as surely indicating the presence of ice sheets in those low latitudes and at that early time, but the evidence under constantly renewed and broadened scrutiny by trained glacialists steadily grew till it became irrefutable. There seems now no rational escape from the conclusion that mantles of ice covered large areas in the peninsula of India, in Australia, in the southern part of Africa, and in South America close upon the borders of the Tropics at a time roundly halfway back to the beginning of the readable record of life.

On the basis of evidences of like kind and cogency, Strahan and Reusch, independently, have reported glacial beds in Norway at a much earlier geological horizon, but one not closely determinate. Willis and Blackwelder have described glacial deposits of early Cambrian age in the valley of the Yangtse in China in latitude as low as 31° N. Howchin and David have described glacial formations of similar age in Australia. In the last two cases the glacial beds lie beneath strata that bear Cambrian trilobites; in other words, they are at the very bottom of the fossil-bearing sediments, 15 periods back, or 75,000,000 years ago, on our rough scale. Prof. Coleman has offered what he deems good evidence of glaciation much farther back at the base of the Huronian terrane in Canada, but some skepticism as to the interpretation still lingers.

Even more pointedly than the epochs of aridity previously cited do these early epochs of glaciation seem irreconcilable with the old view of a hot earth, universally wrapped in a vaporous mantle in early times. They favor, if they do not force, the alternative view that the ancient climates were marked much as the more modern ones have been by periodic and local oscillations and intensifications, and that life was able to survive all of these in some part of the globe, if not in most parts. This warrants the hope, if not the belief, that life may survive similar oscillations and intensifications again and again in the future as in the past.

At the present time glaciation in the polar regions and on Alpine heights is contemporaneous with desert conditions in extensive belts where the systematic circulation of the atmosphere favors aridity. There are reasons for thinking that in the past glaciations and aridity were related to one another in some similar way, and that they cooperated to give an aspect of marked vicissitude to the climates of certain geological epochs. It is to be observed, however, that the epochs of glaciation now known are fewer than the epochs of aridity, and it is probable that aridity has been a more common phenomenon than glaciation.

Set over against the adversities of desert and ice there were stages, as already noted, when abundant life, bearing all evidences of a warm-temperate or subtropical habitat, flourished in high latitudes. In Greenland, Spitzbergen, and other Arctic lands—and we have recently learned also in Antarctic lands—are found relics of life not known to be able to live except in a genial climate. These quite clearly point to subtropical conditions at certain former times where only frigidity now reigns.

In the light of these contrasted states of ice and desert on the one hand and of geniality and moisture on the other, intervening between one another in unexpected latitudes, we seem forced to the view that profound climatic alternations followed one another throughout the whole stretch of known geologic time. These may have been attended by variations in the constitution, as well as the condition of the atmosphere.

If we turn to the relations which the great waters have borne to the great lands, an analogous series of oscillations is presented; and there is ground to suspect that the oscillations of the climates had some casual connection with the oscillations of the land and sea. At no time since life began is there clear evidence of the absence of land, and certainly at no time is there evidence of the absence of an ocean, whatever theoretical views may be held of the earliest unknown ages. The conviction seems well sustained that the land areas of the Archean and Proterozoic eras were comparable to those of the present day both in extent and in limitations, in the sense that they were neither universal nor absent in these earliest known times. Following down the history, the lands seem at times to have been larger and at other times smaller than now. There appears to have been an unceasing contest between the agencies that made for the extension of the land and the agencies that made for the extension of the sea. While each gained temporarily on the other, complete victory never rested with either. From near the beginning of the readable record there appears to have been an unbroken continuity of land life, and from a like early stage an unbroken continuity of marine life. Probably the history of both goes back thus unbroken

far into the undeciphered eras which preceded the readable record, and no one to-day can safely affirm the precedence of either over the other on the basis of the physical record, either in time or in genesis, whatever his theoretical leanings may be.

Among the agencies assignable for the extension of the land are such as deform the earth and by deepening its basins and increasing its protrusions draw the water into the deeps and give relief and extent to the land. Among the agencies that make for the extension of the sea are the decay and erosion of the surface of the land and the girdling cut of the waves about its border. By the unceasing work of these gentle, but persistent, agencies, the land is brought low and the sea creeps out upon its borders. If the deforming of the earth body were held in abeyance for an indefinite period, the lowering of the land, the filling of the basins by the inwash and the spreading of the sea would inevitably submerge the entire surface of the globe and bring an end to all land life. Great progress in such sea transgression took place again and again until perhaps half the land was submerged, but before land life was entirely cut off or even very seriously threatened a regenerative movement in the body of the earth took place, the land was again protruded and extended and the sea again restricted.

Here, then, also, there have been a series of reciprocal movements which, while they have brought alternate expansions of land life and of sea life, have notwithstanding conduced to the preservation of both under shifting stimulating conditions, and have thus maintained the continuity of the two great divisions of life, if indeed they have not promoted the evolution of both by alternate stress and tension.

It appears, then, in the large view that in each of the great groups of terrestrial conditions on which life is dependent, there has run through the ages, vast as they have been, a series of oscillatory movements that have brought profound changes again and again, but which have never permitted any of the disasters that seemed to be threatened by these movements to go far enough to compass the general extinction of life. These reciprocal movements seem to be dependent upon a balancing of the actions of the opposing agencies that has the aspect of a planetary equilibrium. It does not seem to me too much to regard it as an automatic regulative system. A clear insight into the intimate workings of the complex of agencies that cooperate in this regulative system is rather a task of the future than an attainment of the present, and I am not now justified in offering more than suggestions of what may prove to be among the main features of the system, in the hope that you will receive them with due reserve.

The feature of profoundest importance from our racial point of view, the maintenance of the land against the incessant encroachments of the sea, seems to be assignable to internal agencies which at periodic intervals bring about a deformation of the earth's body and a readjustment of the waters on its surface to the changed capacities of its basins. These actions involve changes also in the contact of the air with the earth substance which increases or diminishes the consumption of the air by chemical combination. At the same time, these deformations are probably related to volcanic and other extrusive actions which feed the atmosphere. How far this volcanic feeding is merely a return to the air of what had been absorbed earlier it may not be safe here to say, as opinion is not yet at one on this point, though the force of growing evidence seems to imply that at least a notable part of the volcanic gases are original. Final opinion on this point is dependent on what views shall ultimately prevail respecting the conditions in the interior of the earth, and these in turn are much dependent on the mode of origin of the earth. Perhaps it will be generally agreed that feeding from the interior is one of the sources of atmospheric supply, and that it helps to offset the depletion caused by chemical union with the earth substance; in other words, that the earth body gives out as well as takes in atmospheric material. It is not apparent, however, that there is any special automatic balancing of these opposite processes, such as appears to be requisite for maintaining the delicate adjustment on which the secular continuity of life depends.

The ocean acts as a regulator of the atmosphere by alternately absorbing into itself and giving out atmospheric gases under the control of the equilibrium that exists between the gases in the water and in the air. This action is automatic and appears to be important. It has, however, its peculiarities and its limitations, and it does not seem to be wholly adequate, even when added to the preceding agencies.

If it is possible at the present stage of inquiry to point to an additional automatic action that promises to supplement the preceding in such a way as to make up a competent regulative mechanism, it seems to me most likely to lie in the high speed necessarily attained by some of the molecules of all atmospheres which causes them to escape from the gravity of the body about which they are gathered and to fly off into the sphere of control of some adjacent body, thus giving rise to an interchange of atmospheric matter. It seems safe to affirm that such interchanges prevail, but it remains to learn how effective these interchanges may be. The results of personal inquiries that have been in progress for some time have not yet been submitted to the full criticism of those best qualified to test them, and they can

only be drawn on here with reservation, but they seem at least to promise important help in solving the problem of a regulative system.

A close analysis of the movements of the molecules of the outer atmosphere leads to the belief that the prevailing states there are distinctly different from the collisional states that prevail near the earth. The movements in the outer atmospheres seem to be in an essential part orbital in nature, and this orbital atmosphere may logically be supposed to occupy in an extremely attenuated way some large part of the whole sphere of the earth's control. There should, under the same reasoning, be a similar orbital extension of the atmosphere of the sun, and this extremely attenuated extension of the sun's atmosphere should embrace the earth and its atmosphere. Under the laws of molecular activity, these two atmospheres should be interchanging molecules at rates controlled by the equilibrium that exists between them. It is logical to infer that any excess above this state of equilibrium that may at any time come to affect the earth's atmosphere would cause it to feed out into the sun's sphere of control faster than the reverse feeding took place, and that any deficiency relative to the equilibrium state that might at any other time come to affect the earth's atmosphere would lead to a deficient feeding out while it would facilitate a greater feeding in from the sun's orbital atmosphere. If this logical inference is valid, and if it has the requisite efficiency—which is a vital question yet to be settled—the maintenance of the delicate atmospheric conditions requisite for the continuity of life is automatically secured by a cosmic process of a fundamental nature. Under this view the future competency of our atmosphere is not left wholly dependent on losses and gains at the earth's surface, but is abetted by a system of solar and interplanetary exchanges of a broadly cosmic order. The endurance of the earth's atmospheres is thus in a measure wrapped up in the continued efficiency of the sun's activities.

If the question of our future be thus wrapped up in the problem of solar endurance, weight must be given to the fact that the sun is sending forth daily prodigious measures of energy. But yet these are not wholly without some gains by way of partial offset. So far as present knowledge goes, however, the gains are greatly inferior to the losses. So long as the radiance of the sun was supposed to be dependent on ordinary chemical action, or on the fall of meteorites, or on self-contraction, it did not seem possible to forecast an endurance of activity sufficient for the direct and indirect needs of terrestrial life beyond a few million years. These few million years of probable endurance were of course a great advance on the estimates of the endurance of terrestrial conditions suitable for life worked out on the old method of estimate. But recent physical investiga-

tions of a revolutionary character have disclosed sources of energy in radioactivity of an extremely high order. In the light of these disclosures, the forecast of the sun's probable power to energize sufficiently the activities of its own atmosphere and of ours, and to warm the earth adequately, is raised to an indeterminate order of magnitude.

We thus find grounds for a complacent prophecy of the earth's future habitability. This prophecy seems to me to gain strength from its appeal to a series of reciprocities between land and sea, between earth and air, and between the planet and the solar center that seem to have been potent in all the history of the earth from its genesis to the present time.

But if traditional fears from these domestic sources be dismissed, may we hold ourselves free from impending dangers from the heavens without?

So far as present knowledge goes, one tangible possibility of disaster from without our system seems to be contingent; the possibility of collision with some celestial body, or, what is many times more contingent, such a close approach to some massive celestial body as to lead to serious disruptive effects. Within the solar system, the harmonies of movement already established are of such an order as to give assurance against disaster for incalculable ages. Comets do indeed pursue courses that may, theoretically at least, bring about collision, but comets do not usually appear to possess masses sufficient to work disaster to the life of the earth, as a whole, whatever local catastrophies might be suffered at the points of impact. The motions of the stars trend in diverse directions, so that collisions and close approaches between them seem, theoretically, possible and probable, if not inevitable. There are in the heavens also many nebulæ and perhaps other forms of scattered matter, and there are doubtless also dark bodies, all of which offer possibilities of collision. The appearance of new stars flashing out suddenly and then gradually dying away suggests the actual occurrence of collisions or disastrous approaches. Though these seem destructive on their face, and are so, no doubt, it has been held that the close approach of suns is one of the regenerative processes of the heavens, and that by it old planetary systems are dispersed and new systems brought into being. One phase of the planetesimal hypothesis is built on this conception. It postulates the close approach of some massive body to our ancestral sun long ago, and that by this approach the sun's former planetary system, if it had one, as is thought probable, was dispersed, and at the same time the matter for the present planetary system was thrown out into a nebulous orbital state by the explosive power resident in the sun aided by the differential pull of the great body that was

passing near. However this may be, it must be conceded that in collision and close approach lie possibilities of ultimate disruption to the solar system and disaster to our earth.

But here, as in other vital issues, the degree of danger is determined by the time elements involved. How imminent is this liability to disaster?

The distances between the stars are so enormous that the contingencies of collision or disastrous approach are very remote. Although nothing but rough computations can be made, and even these must be based on assumptions whose validity is open to doubt, the chance of a given sun or planetary system falling on disaster from collision or close approach seems to be of some such order as once in some few billions of years. There is no star whose nearness to us or whose direction of motion is such as to appear to threaten the earth at any specific time in the future. There is only the general theoretical possibility or probability when time enough is allowed.

While, therefore, there is to be, with little doubt, an end to the earth as a planet, and while perhaps previous to that end a state inhospitable to life may be reached, the forecast of these contingencies from the point of view herein taken places the event far ahead in the indeterminate future. The geologic analogies give fair ground for anticipating conditions congenial to life for millions or tens of millions of years to come, not to urge the even greater possibilities.

This answer to the question of the future habitability of the earth, even if the conditions remain congenial to man, does not necessarily carry the actual realization of the future opportunities thus open to our race. Congenial conditions granted, there still arise questions as to man's continued biological adaptation, as to the tenacity of his vital powers and as to the consequences of his own choices of action. If an appeal be made to the record of the animal races for an argument from analogy, it is easy to find some cases of marvelous endurance and some cases of very short records, while the majority fall between these extremes. Many families of animals persisted for millions of years, and the average record known to us is much greater than the record already made by man. On historical grounds, then, a long career can not be denied to man—neither can it be assured. It is an individual race problem. It is a special case in the problem of races in the largest sense of the term.

In distinction from the animal races, two new factors of deep import enter into the problem of human endurance, one the power of a definite moral purpose, and the other the resources of research. No previous race has shown clear evidence that it was guided by moral purpose in seeking ends not immediately before it and not connected with its physical requirements. In the human race such moral purpose has risen into a declared distinctness. As it grows

with the higher development of the race, beyond question it will count in the perpetuity of man, or of the superman into which he may evolve. No doubt it will come to weigh more and more as the resources of helpful and harmful indulgence are increased by human ingenuity. New issues will arise as man is put to trial by new temptations to the deleterious and new promptings to rectitude. Organic ethics will quite certainly become more critical in deciding the strains that shall live on and the strains that shall perish, as the growing multiplicity of numbers brings upon the race with increasing stress those phases of the struggle for existence that are distinctively human. The ethical factor will, beyond question, be more fully recognized as a source of perpetuity or as a cause of extinction, according as the criterion of the survival of the fittest shall render its unimpeachable verdict on what is organically good and what is organically evil, as determined by the actual working test.

But to be most efficient, moral purpose must not only be shaped by the highest intelligence, it must be united in action with specific knowledge of the conditions under which it works and of the agencies which it may control. Herein lies the function of research, for research is to be looked upon as the sole reliable means of trustworthy knowledge. None of the earlier races made systematic inquiry into the conditions of life, nor did they consciously seek thereby to protract their racial careers. What can research yet do for the extension of the career of man? We are witnesses of what it is beginning to do in making the forces of nature subservient to man's purposes and in giving him command over the maladies that hedge him about. Can research master the secrets of vital endurance; can it reveal the mysteries of heredity; can it disclose the fundamental processes that condition the longevity of the race? The answer must be left to the future; but I take no risk in affirming that when moral purpose and research come to be the preeminent characteristics of our race by voluntary adoption and by the selective action of the survival of the fittest, and when these most potent attributes join in an unflagging endeavor to compass the highest development and the greatest perpetuity of the race, the true era of humanity will really have been begun.

WHAT IS TERRA FIRMA?—A REVIEW OF CURRENT RESEARCH IN ISOSTASY.

[With 3 plates.]

By Bailey Willis.

What are the foundations of the earth? On what do mountains, continents, and ocean basins rest? When men build they look to it that the foundations are firm enough to support the weight of the structure, or the building crushes its foundation and falls. Are there any rocks firm enough to bear the weight of mountains or continents without crushing?

The crushing strength of rocks, as ascertained in a testing machine, varies from 8,000 to 20,000 pounds to the square inch, and their average density is such that the weight of a column 3 to 5 miles high would crush its base. But among mountains there are many that are more than 3 miles high and some that exceed 5 miles. Their pyramidal form aids that portion of the foundation which is beneath the high peaks, but it has nevertheless been observed in tunneling that the rocks are in a state of great strain, as was the case, for instance, with the granite penetrated by the Simplon Tunnel beneath the Alps.

In the case of a plateau the form is that of a block, and where the height exceeds 3 miles the base probably approaches a crushed condition. Tibet thus stands above the general level of the Asiatic Continent. Asia itself may be described as a plateau, having an uneven surface, but rising on the average 3 to 4 miles above the bottoms of the ocean basins. Considered, then, as a mass whose base is on a level with the depths of the oceans, Asia is so high that its weight must exceed the load which can be supported by rocks, as we know them. The same is true of other continents.

Thus it seems reasonable to think that the foundations or rocks beneath the continents may approach a crushed condition or may actually be crushed.

Our thought has passed from mountains to plateaus and to continents. The foundations of continents comprise one-fourth of the

earth's outer crust. The three-fourths which underlie the ocean beds obviously are no exception to the conditions described. At depths of 3 miles or more the rocks beneath the ocean basins must also be loaded beyond the strength of rocks at the surface and must approach a crushed condition.

This crushed condition is not, however, that of rocks which fall apart when crushed, for the foundations of continents and ocean beds are part of the solid earth and are continuous all about the sphere. There is, therefore, no space into which any crushed mass may crumble. The strength of the rocks may be overcome, but they can not fall apart. This condition has been reproduced experimentally and it has been shown that marble and even the firmest granite may be forced to change form, yet be held to a coherent solid. The rock under these conditions may be compared to wax, if only we bear in mind that it remains all the time a very strong solid.

The zone of crushing without separating has been called the zone of flow or flowage, because the movement of any rock mass under such pressures is compared with that of a very stiff fluid. But the word flow conveys an idea of mobility, and is thus misleading. It is necessary constantly to insist that rocks in the zone of flowage are rigid solids.

Solution plays an important part in the flow of rocks. Not that any large mass is dissolved at any particular time, but by the solution of a minute grain or molecule, which then flows from the point at which it was dissolved to a point where it is redeposited. The condition which causes solution is a slight excess of pressure or of temperature or both; and deposition from solution follows where these slight excesses disappear. Rocks are composed of mineral particles which differ widely in solubility and under adequate differences of pressure the less soluble may be granulated microscopically, whereas those crystals which are soluble in any moisture or mineral solution that may be present are dissolved and then recrystallized on a point that is less hard pressed. The individual element of motion is microscopic or even molecular, but the sum total of movements may affect a mass of subcontinental dimensions during a geologic epoch; that is to say, during a million years or several million years, more or less.

Movements in the foundations of continents are exceedingly slow.

In the zone of crushing, any rock mass of limited horizontal dimensions may be regarded as the base of a column that reaches to the surface of the earth. Being crushed by the weight of the superincumbent mass it seeks to spread sidewise; but it can not because each adjacent mass, which is the base of an equally heavy column, also seeks to spread in the same manner and to the same degree. If at any depth in the zone of crushing one mass be under a heavier load

than that borne by another adjacent to it, then the base of the heavier column will tend to spread with greater horizontal force than that exerted by the lighter column; but in order to cause movement, the excess of thrust from the heavier must be greater than the strength of the rocks under the lighter load. The last conclusion follows because the material against which the excess of horizontal pressure is directed is held to the condition of a rigid solid by the very load that crushes it.

It may seem as though the approximate balance of lateral pressures in the foundations of mountains, continents, and ocean basins were sufficient to explain the apparent stability of terra firma. But it will not have escaped attentive thought that the pressure beneath the mass of the Tibetan Plateau is sufficient to cause rocks at its base to spread near sea level. Or that the continental plateaus stand so high that their weight approaches the crushing strength of ordinary rocks near the level of the oceanic plateaus beneath the waters. Any lateral pressures, which may exist at these levels, are not opposed by lateral stress from an adjacent mass and stability depends upon the firmness of the rocks. Since the Tibetan Plateau and others stand, and since continents are stable, at least during very long periods of time, it would seem that rocks under these great loads must be stronger than the same rocks in the testing machine. This is no doubt to a certain extent true, and there is some experimental evidence to show that the rigidity of rocks increases greatly under high pressures.

The resistance which any solid offers to a permanent change of form is known to physicists as the viscosity of the solid, and it may safely be said that the viscosity of a solid increases under pressures applied from all directions in some ratio for each particular substance that is as yet unknown, but which, no doubt, gives the rigidity of steel to rocks a few miles below the surface of the earth.

Here we must introduce the idea of time. There is evidence to indicate that the huge masses of continents are not firm enough to maintain their altitude permanently; that in the lapse of ages they do spread laterally with a glacier like motion; and that the spreading lowers the surface. When this happens to a continent that has already been reduced by erosion to a low plain, the conditions are peculiarly favorable for submergence of the land beneath the sea, as has repeatedly occurred in the history of continents.

There is, furthermore, abundant evidence to show that at other times the bases of continents have been compressed laterally, squeezed, as it were. This effect has long been attributed to a contraction of the earth in cooling, as was first suggested by Dana, but the advances of geologic knowledge have greatly strengthened an old objection—namely, that contraction by cooling is inadequate to account for the

amount of compression which the continents have suffered. While we know that continents have been squeezed, it is not known that ocean beds have been similarly affected. The broad flat ocean bottoms have rather the form of surface of a mass which flattens and spreads under its own weight. The writer has suggested that the spreading masses below the oceans may squeeze the masses beneath the continents, and finds a cause therefor in the fact that a cubic mile of the former is heavier than one of the latter. This brings us to the idea of differences of density in the earth's crust.

As far back as 1830 an English physicist, Airy, entertained the idea that some parts of the earth's crust might be heavier, some lighter, and in 1855 he contributed the suggestion to a discussion by Pratt of the attraction exerted by the Himalaya Mountains. In course of surveys in India it had been found that the great mass of that mountain range exerts an attraction, which was, however, much less than it should be according to calculation, if the mass beneath the Himalayas were of the same density as that beneath the peninsula of India. Hence Airy and Pratt suggested that the mountains must be lighter.[1]

When Pratt wrote in 1885 no one doubted but that the earth had cooled from a molten condition, become covered with a rigid crust, and finally assumed its present configuration with all the detail of ocean basins, continents, and mountains. Although Pratt and Airy did not wholly agree, they both explained the lightness of the mountains by reasoning based on the processes of cooling and floatation of the crust on the still fluid interior. Now that it is known that the earth has the rigidity of steel and can not possibly be liquid within, the basis of their reasoning has disappeared and their theories are no longer entertained; but the inference as to the lightness of the mountains has been confirmed not only in regard to the Himalayas, but for many other mountain ranges. It has also been shown that continental masses are relatively light as compared with those beneath the oceans. And it follows that if we think of a column beneath the continent and one beneath the ocean extending down to a common level, the taller column of lighter material can be of the same weight as the shorter column of heavier material. The two columns might then balance each other or be in equilibrium.

It seemed probable to Dutton and Gilbert 20 years ago that this relation of equilibrium was characteristic of the masses that make up the outer earth. Dutton discussed the problem in the following terms:

If the earth were composed of homogeneous matter, its normal figure of equilibrium, without strain, would be a true spheroid of revolution; but if

[1] Pratt, J. H. A treatise on Attractions, Laplace's Functions, and the Figure of the Earth, 4th ed., pp. 93–94, 1871.

heterogeneous, if some parts were denser or lighter than others, its normal figure would no longer be spheroidal. Where the lighter matter was accumulated there would be a tendency to bulge, and where the denser matter existed there would be a tendency to flatten or depress the surface. For this condition of equilibrium of figure, to which gravitation tends to reduce a planetary body, irrespective of whether it be homogeneous or not, I propose the name isostasy. * * * We may also use the corresponding adjective, isostatic. * * * The question which I propose is: "How nearly does the earth's figure approach to isostasy?"[1]

Gilbert,[2] in a measure, proposed an answer to Dutton's question. He had been engaged in original studies of the rigidity or strength of the earth's crust and had calculated that there was a limit to the mass which it could support without yielding. He expressed his view very conservatively, saying:

It is believed that the following theorem or working hypothesis is worthy of consideration and of comparison with additional facts: Mountains, mountain ranges, and valleys of magnitude equivalent to mountains, exist generally in virtue of the rigidity of the earth's crust; continents, continental plateaus, and oceanic basins exist in virtue of isostatic equilibrium in a crust heterogeneous as to density.

Researches as to the distribution of lighter and denser masses in the outer earth have been greatly extended and highly refined since 1889. Dutton's general law is recognized as true. The larger elevations and hollows of the earth's surface are due to the balance of lighter and denser masses. Gilbert's suggestion that mountain-like masses and hollows are rigidly supported, commands consideration by conservative students. It is, however, apparently contradicted by the exhaustive calculations of the geodesist, Hayford, who concludes that the balance postulated by Dutton extends to masses which are much smaller than any which Dutton or Gilbert regarded as probably in equilibrium. In order to understand the present state of the problem we may briefly review the methods that have been employed in making observations.

Gravity is the force which causes bodies to fall toward the earth or a pendulum to swing. Its intensity may be measured by the velocity attained by a falling body at the end of a second, or by the number of swings that a pendulum of definite length will make in a definite time. The latter method of measurement is capable of very great accuracy and is used for all observations of the intensity of gravity on land. In order that the determinations may attain the desired precision and yet be carried out within a reasonable time, a highly specialized apparatus is used. The form employed by the Coast

[1] Dutton, C. E. On some of the Greater Problems of Physical Geology. Phil. Soc. Wash., Bull., vol. 11, pp. 51–64, 1889.

[2] Gilbert, G. R. The Strength of the Earth's Crust (abstract). Geol. Soc. Am., Bull. vol. 1, pp. 23–25, 1889.

and Geodetic Survey is shown in plate 1.[1] A set of invariable pendulums is swung in an air-tight case in a partial vacuum, at a uniform temperature. An electrical flash apparatus makes the half-second beats of a chronometer visible and permits the observer to note when the beat coincides with a swing of the pendulum. The time of oscillation of the pendulum at the station where the intensity of gravity is to be ascertained is compared with the time of oscillation under identical conditions at a station at which the intensity is known. The desired value of gravity is then calculated.

The value thus obtained for the intensity of gravity at any particular place can be compared with the intensity at other places only by making all the conditions of attraction the same for both places. Let it be supposed that any two results which are to be compared have been obtained at stations that differ in latitude, in altitude above sea, and in topographic surroundings. Then account must be taken of all these conditions.

Latitude and altitude both affect the distance from the earth's center and gravity varies inversely as the square of that distance. Hence observations are reduced to sea level and are then compared with the normal value of gravity for the latitude of the observation according to a formula constructed by the German geodesist, Helmert.

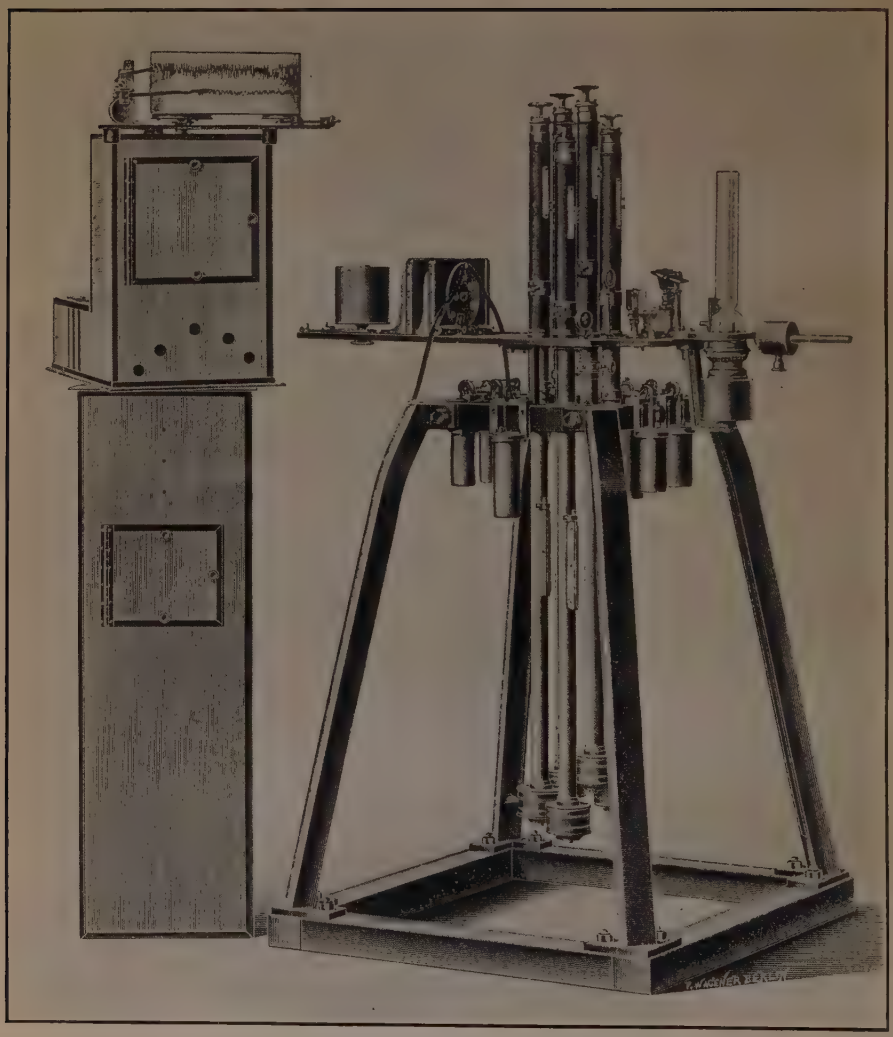
Suppose, for instance, that an observation for gravity had been made in a balloon over the sea. It would be necessary to correct the result for the altitude of the balloon and compare with the normal value given by Helmert's formula for that latitude. This is what has been called the "free-air reduction." It is always made.

The calculation of the influence of position and topographic surroundings involves theoretical postulates which distinguish three different methods. One may be described as the method of high rigidity, since it rests upon the postulate of a rigid earth of uniform density. The other two both develop from the assumption of isostatic equilibrium, but they differ in that according to one the balance is supposed to be complete, but according to the other it is partial. An illustration may serve to make the distinctions clearer.

Let us transfer the place of observation from the balloon over the sea to the top of a lighthouse rising from sea level. The reduction for elevation, the "free-air reduction," must be made as before, but correction must also be applied for the mass of the lighthouse, which is an excess of material, added to and rigidly upheld by the rocks at sea level. It exerts an additional attraction, which must be deducted from the observed value in order to obtain the true value of gravity at sea level beneath the lighthouse. According to the postulate of high rigidity, all elevations on the earth's surface above

[1] Illustration kindly furnished by Mr. Geo. R. Putnam.

PENDULUM APPARATUS FOR MEASURING GRAVITY.



HECKER'S APPARATUS FOR MEASURING GRAVITY AT SEA.

sea level are excesses of mass which exert a similar extra attraction. A similar correction must therefore be applied to all observations which are calculated under that hypothesis. This was the reasoning of Bouguer, a French mathematician, who calculated the gravity observations made from 1736 to 1739 in Peru. The method is therefore known as Bouguer's method, and the mathematical formula as Bouguer's formula.

Had the lighthouse in this illustration not been an extra mass, added to the rock mass of its foundations, the correction for excess of mass should not have been made. But under the hypothesis of complete isostatic balance there is no excess of mass, since that hypothesis rests upon the assumption that all parts of the earth's crust which are, we will say, a mile square have the same mass, the heights of the columns above some common level within the earth being inversely proportioned to the density of the materials. The common level of the bases of the columns may be 100 miles below sea level, or it might be the center of the earth. All columns of the same cross section rising from it to sea level or to the heights of the Himalayas have the same mass by hypothesis. Hence there should be no correction for excess. The assumption of complete isostatic equilibrium is the basis of Hayford's work, which we shall see is the most recent and most exhaustive investigation of the subject. We shall therefore refer to the method of reduction based on it as Hayford's method.

Some thinkers on this subject hold that isostatic equilibrium can not be complete for every hill and valley of the surface, nor even for every mountain. They admit, however, the assumption that extensive masses, such as that of a whole mountain range or plateau, and defects of mass, such as that of the basin of the Black Sea, may be compensated or in equilibrium. The reasoning in this case proceeds on the basis that the mass of any large feature would be balanced at the altitude of a "mean plain," which is a hypothetical plain, that would be produced by leveling off the hills till the mass removed from them just filled the valleys. The total mass remains unchanged, since nothing has been added and nothing subtracted. The position of the mean plain depends upon the irregularities of the surface and is independent of the altitude of the station at which the observation for gravity is made. The mean plain may therefore lie above or below the station. If it lies above, there is a mass between the two which exerts an upward attraction and reduces the observed value of gravity by an amount which must be added to it; whereas if the mean plain lies below the station there is an excess of mass whose attraction is included in the original value observed and for which a deduction must be made. This method was first suggested by a French mathematician named Faye, and is

known as Faye's method; but Putnam and Gilbert were the first to put it in practice and to elaborate the idea of the mean plain.

In the discussion of Hayford's method it will be seen that there is a correction for topography which is analogous to that for mean plain in Faye's method, but which has reference to a "theoretic plain that passes through the station."

The test which is applied to the results of calculations made under any one of these three different assumptions is that of agreement. All the values of gravity calculated by one and the same method should be the same. All the corrections which are applied are intended to eliminate from the original observation those items of attraction which may render the observed value greater or less than the normal value. Any difference which remains points to some factor that has been overlooked or to an erroneous assumption. That method of reduction which yields results in closest accord with each other is assumed to be nearest the truth.

We shall first contrast the assumption of high rigidity with that of partial isostatic balance combined with partial rigid support; and then compare the latter with the assumption of completed isostatic balance, referring to the three methods, respectively, by the names of their authors, as Bouguer's, Faye's, and Hayford's.

In Bouguer's time no one doubted but that the earth's crust was very rigid. All masses above sea level were regarded as heaps upon the rigid crust and all depressions below sea level were taken to be defects of mass in the spheroid whose surface should correspond with that of the sea. Bouguer therefore corrected all observations for gravity by subtracting the attraction of the mass between the station and sea level. He obtained very small values. The intensity of gravity appeared to be so slight that Laplace, in the Mecanique Celeste, calculated the density of the material beneath the Andes as about equal to that of water, and he gravely suggested that the observed lightness might be due to great caverns within the volcanic zone. This suggestion is now recognized as quite untenable since rocks are not strong enough to maintain open spaces under the pressures that exist beneath the Andes.

A great many observations for gravity were made during the century and a half between 1739 and 1895, and all, so far as the writer knows, were reduced by Bouguer's method. They yielded a general result: The intensity of gravity on continents was found to be less than normal and was particularly low on high mountains; whereas the intensity was great on oceanic islands. Hence followed the conclusion that continents are light and suboceanic masses heavy.

But Bouguer's method yielded extreme results. Oceanic masses appeared to be very heavy and continents seemed excessively light, as Laplace's calculation of the density of the Andes should have

shown. The anomalies resulting from Bouguer's formula led Faye, in 1880, to suggest that the correction for the attraction of the mass between the station and sea level should be omitted. He reasoned correctly that this mass is balanced and therefore is not equivalent to a weight which is carried by the rigidity of the crust. He distinguished between the masses which are "compensated," or, as we now say, balanced isostatically, and those which are in the nature of loads superimposed upon the crust, and he wrote:

> It must be clearly understood that even if the thickness of the continents above the sea has no place in the computation, this is not true, for example, of the mass of the great pyramid of Egypt, if one were to observe the oscillations of the pendulum at its summit. In that case, after having reduced the observation to the level of the sea, it would be necessary to subtract the effect of attraction of the pyramid above the level of the ground. In the same manner, if Bouguer had carried his pendulum to the summit of Pechincha, 1,500 meters above the level of Quito, it would be necessary to take account of the attraction of this mountain upon the pendulum of Bouguer.

It will be noted that Faye regarded the mountain Pechincha as a mass upheld by rigidity, but considered compensation or balance to be the condition of the larger mass below the plain of Quito. He had thus been led by studies in geodesy to views which Gilbert reached in 1889 by independent geological investigations. But Gilbert went further than Faye. He estimated the magnitude of the mass which the earth would support rigidly and placed it tentatively between 400 and 600 cubic miles.

Faye's method was first employed by Putnam in 1895 and independently by Gilbert, who collaborated with Putnam in the study of gravity observations made in the United States under the Coast and Geodetic Survey.

Putnam's results were also calculated according to Bouguer's method by Gilbert as well as by himself. The comparison with Faye's method was greatly in favor of the latter, as the values obtained by Faye's method were much more accordant, when reduced to sea level and the same latitude, than those obtained by Bouguer's from the same observations. The comparison was so much to the disadvantage of the older method that it may be said to be no longer worthy of consideration, and the very many results reached by it are of relatively slight value.

The accordance of results by Faye's method was so satisfactory that Putnam and Gilbert may be credited with having established beyond question the principle of isostasy as applied to the larger features of relief of the earth's surface. The small number (35) of stations considered by them and the limitations necessarily placed upon the computations for corrections nevertheless lessen the value of their estimates as to the load that the earth could bear rigidly.

Putnam himself stated in his article that the residuals obtained by his computation was not precise.

In order to understand this qualification of their results it is necessary to consider the method of reducing the "mean plain." The position of that plain is such that the masses represented by hills, mountains, or plateaus above it are equal to the defects of mass represented by valleys or wider depressions below it. The position is calculated from topographic maps, whose accuracy thus enters into the computation, but a more important factor is the radius of the area about each station to which the estimate is extended. Gilbert took a radius of 30 miles and Putnam a radius of 75 miles, both investigators being limited by the labor of computation to a smaller area about each station than they would have chosen. Hayford has since shown that the attractions due to topographic features out to a distance exceeding 2,500 miles are not negligible, and for a work on the intensity of gravity in the United States, which is the latest published, he has extended the computations to the features of the entire globe. Thus the detailed residuals of gravity, the differences from the normal, obtained by Putnam and Gilbert, are suggestive rather than precise. Those investigators proved the isostatic balance of large features, but they did not demonstrate how small a feature may be isostatically balanced or how large a feature may be rigidly supported.

We have thus compared the hypothesis of high rigidity of the earth's crust with that of partial isostatic balance, entirely to the advantage of the latter. There remains the hypothesis of complete isostatic compensation, which postulates that all parts of the earth are nicely balanced. Hayford has employed this assumption as the basis of the most refined and extensive investigations as yet made on the subject.

The data which he has used are derived from the work of the United States Coast and Geodetic Survey and the computations have been executed by that organization. There are two elaborate investigations. One relates to deflections of the plumb line from the true vertical as determined at 507 stations of the precise triangulation which is the basis of the geodetic survey of the United States.[1] The other investigation relates to observations with the pendulum for gravity.[2]

Deflections of the plumb line are determined in precise triangulation by comparing the direction of the apparent vertical line with the true vertical which is fixed astronomically.

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[1] Hayford, J. F. The figure of the earth and isostasy from measurements in the United States. U. S. Coast and Geodetic Survey, Washington, 1909.

[2] Hayford, J. F. Supplementary investigation in 1909 of the figure of the earth and isotasy. Coast and Geodetic Survey, Washington, 1910.

The deflection is due to lateral attraction, which may be exercised by mountain masses or by dense bodies within the earth's crust lying on one side of the station, or by both sources of attraction. The influence of topographic features, whose masses are more or less accurately determinable, can be calculated. There then remains a residual attraction which is presumably due to a dense body, but before accepting that conclusion it is necessary to eliminate any erroneous assumption that might have a similar effect.

Among the subsidiary investigations which Hayford made was one relating to the depth below sea level at which all the columns which extend downward from the earth's surface are balanced. At one extreme he calculated the values of gravity on the assumption that this depth, which is called the depth of compensation, is zero; that is, there exists immediately below every elevation the full compensating defect of density and below every depression the full compensating excess of density necessary to balance the inequalities of height. At the other extreme he calculated the values of gravity on the assumption that the depth of compensation is infinity; that is to say, the earth is so rigid that there is no compensation in the finite radius. He also made similar computations for intermediate depths of the level of compensation. That which gave the most accordant values of gravity and which is therefore regarded as most reliable was at first ascertained to be 114 kilometers, but was subsequently corrected to 120.9 kilometers. Helmert has arrived at the value of 123 kilometers by independent computations. There is, therefore, no doubt but that this value commands a certain confidence under the primary assumption of complete isostatic compensation. It may, however, be regarded as an average, from which there are in fact greater or less variations in different localities, and it also depends upon the postulate that the density of each individual column remains the same from the surface to the bottom at 123 kilometers. It is more probable that the density increases downward, and this would somewhat modify the value of 120.9 kilometers. Nevertheless this conception of a definite lower limit to the zone of compensation is of the highest value. At and below that depth all pressures due to gravity are by hypothesis equal.

In calculating the topographic correction before making the various computations for the depth of compensation, Hayford took account of all irregularities of the earth's surface to a distance of 2,564 miles from each station in all directions. The immense labor of these computations was brought within practicable limits by special methods devised to that end. As the stations ranged in position from the Atlantic to the Pacific coast, the depths of the Atlantic and Pacific basins were included among the features considered, as well as

the highlands and mountain ranges of the continent. In the direct studies for gravity the scope of these computations has been extended to the features of the entire earth.

This topographic correction in Hayford's investigations occupies the place which the calculation of the "mean plain" takes in those of Putnam and Gilbert. But the plain of reference for the topographic correction under the assumption of complete isostatic compensation is the "theoretic plain" at the altitude of the station indefinitely extended in all directions. The mean plain and the theoretic plain will rarely if ever coincide, and the corrections therefore have different values. It is much to be desired that the "mean plain" correction and Faye's method, as used by Putnam and Gilbert, should be applied to all available data with the scope and detail employed by Hayford in order that we may have a comparison of the two methods on equally reliable results. The reason for this statement will appear presently in considering certain geological data that bear on the choice of method.

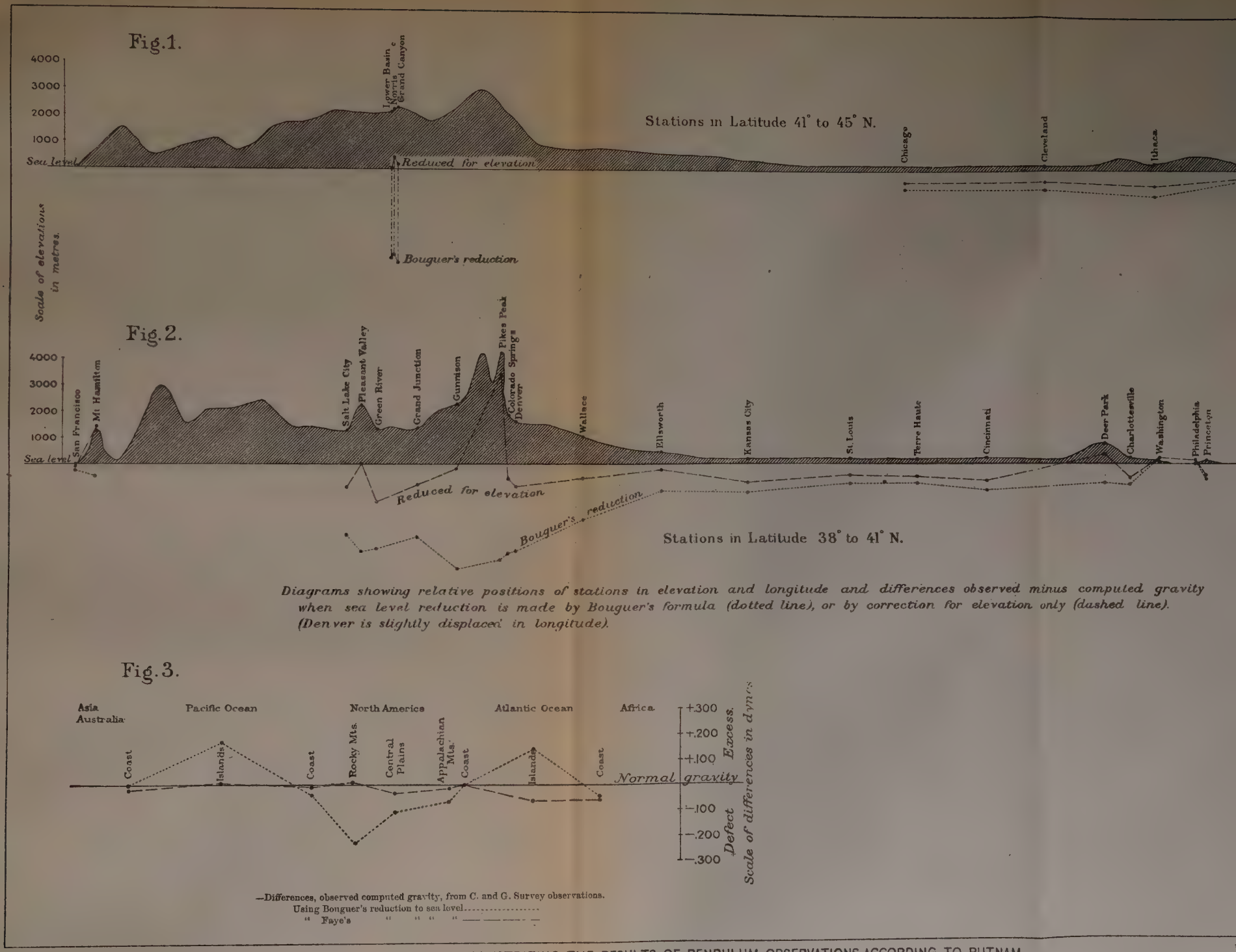
Hayford found that at each station there remained residual deflections of the plumb line after all the corrections had been made, and he regarded these residuals as evidence of departures from complete isostatic compensation. He says on this point:

> For the United States and adjacent areas it is safe to conclude from the evidence just summarized that the isostatic compensation is so nearly complete on an average that the deflections of the vertical are thereby reduced to less than one-tenth of the mean value which they would have if no isostatic compensation existed. One may properly characterize the isostatic compensation as departing on an average less than one-tenth from completeness or perfection. This statement should not be interpreted as meaning that there is everywhere a slight deficiency in compensation. It is probable that under some areas there is overcompensation as well as undercompensation in others.

Interpreting the preceding estimate in terms of altitude, Hayford places the average departure for the Continent of North America from that altitude which would correspond to perfect compensation at 250 feet. He further states that the maximum horizontal extent which a feature, such as a mountain, can have and escape compensation is between a square mile and a square degree.

It is evident that Hayford's studies on isostasy exceed all previous ones in exhaustive detail and in precision. Nevertheless there are geological considerations which suggest that the assumption of complete compensation is less satisfactory as a basis of reasoning than that of partial compensation and partial rigidity.

To present these considerations we must proceed from the fact that the features of continents are not permanent. They are the transient effects of two processes, uplift and erosion, which are opposed to each other, and which act intermittently. During certain epochs, of which the present is one, uplift has been dominant. Then continents



Diagrams showing relative positions of stations in elevation and longitude and differences observed minus computed gravity when sea level reduction is made by Bouguer's formula (dotted line), or by correction for elevation only (dashed line). (Denver is slightly displaced in longitude).

DIAGRAMS ILLUSTRATING THE RESULTS OF PENDULUM OBSERVATIONS ACCORDING TO PUTNAM.

have been large and mountain chains both numerous and high. At present continents are unusually large and mountains are unusually elevated. During other much longer periods erosion has exceeded uplift. Then continents have become low and featureless; great plains have prevailed; and in consequence of slight subsidence extensive lands have been submerged. These are facts of the geological record which admit of no doubt.

In this play of processes any particular part of the earth's surface may reach just that altitude at which it is in perfect isostatic balance, but it is not probable that the equilibrium can be long maintained. If the High Plateaus of Utah be in general in isostatic balance, then the Grand Canyon of the Colorado must be too light by the weight of the rock removed in carving it out of the plateau. It is, furthermore, certain that the Grand Canyon is but the beginning of that erosion which will eventually remove as much of the mass of the High Plateaus as lies above a plain, which will slope gently from no great altitude to sea level. If the region is now in isostatic balance, it will then be out of balance. Or, to consider another case: It is a commonly accepted fact among physiographers of the present day that the Appalachian region of the eastern United States was a low plain during the Cretaceous and early Tertiary periods. The plain is now warped up to 4,000 feet, more or less, above sea. If it is now in isostatic balance, it was out of balance during the long lapse of time of the periods named.

It is reasonable to link the movements which are expressed in the warped surfaces of continents with the stresses that are set up by disturbance of isostatic balance. It is probable that the stresses directly or indirectly cause the movements. But the effect is neither immediate nor constant. The disturbing process, erosion, is a very slow process. The plains which it produces endure during a geologic age. The earth is sufficiently rigid to be very slow in responding to the stress.

However, if the hypothetical relation of cause and effect exists between isostatic stress and warping, it is highly probable that equilibrium is most nearly perfect at the culmination of movements of elevation, such as the existing relief presumably represents. Valleys excavated by erosion represent disturbances of that equilibrium, which therefore can not be perfect in detail, or even very nearly so, as Hayford assumes and calculates, but the mass of any large area, such as the Great Plains of central North America, or the High Plateaus of Utah, is very probably nearly in equilibrium, considered as a mass and reduced to "mean plain."

Geological considerations thus afford reason to prefer the method of reduction employed by Putnam and Gilbert, the Faye reduction, rather than that used by Hayford.

The geological evidence which has been cited to show that isostatic equilibrium can not well exist in detail may be regarded as demonstrating a certain rigidity of the earth's crust, which is most severely taxed when erosion has planed away the compensating heights to the nearest possible approach to level plains. It is interesting to note that, per contra, the isostatic balance is probably most nearly complete in regions of most vigorous mountain growth, or for the continents as a whole is most perfect at a time like the present, when uplift is most general. If the disturbing process of erosion could be eliminated from continental activities the uplifts and subsidences would establish perfect equilibrium or a close approach to it. Now erosion has no effect over those portions of the ocean basins which are beyond the reach of the sediments that surround the continents and which occupy nearly three-fourths of the surface of the globe. These areas are depressed because they are heavy, according to the hypothesis of isostasy, and should be depressed more or less according to the density of the underlying masses. The adjustment should be nearly or quite complete except where disturbed by vulcanism or by other special stresses. It is, therefore, of great interest to determine the law of distribution of density beneath the oceans in relation to the depth of the waters, apart from the interest which lies in the comparison of oceanic gravitation with that of continents.

As it is impossible to observe a pendulum on board ship measurements of gravity in ocean areas were restricted to oceanic islands until recently, when they were made possible on the water by a method in which the pressure of the air as shown by a barometer is compared with the pressure of the air as determined by the boiling point of water.

In measuring the air pressure with a barometer the air is balanced by the column of mercury, which will be somewhat shorter at a place where the intensity of gravity is high than at a point where the intensity is less. If the air pressure be measured by observing the boiling point of water, the result is independent of any influence of gravity upon the apparatus. By using both methods at a station the effect of gravity on the barometer at that station can be ascertained, and by comparing the effects obtained at various stations relative intensities are found.

This method, which was originally invented by the German physicist Mohn, was adapted to oceanic work by Dr. E. O. Hecker, who devised an elaborate apparatus for the purpose. It consists of five mercurial barometers which are hung in a metal plate swung on gimbals and which are so illuminated that the movements of the upper surface of the mercury are registered on a photographic film. The record is a wavy line, since the barometers are constantly agi-

tated by the motion of the ship, but with the aid of a special apparatus which registers that motion the effect on the barometer and their actual reading can be ascertained. (Pl. 2.)

Hecker took numerous observations on voyages from Lisbon to Bahia, from Bremerhaven through the Mediterranean and Suez Canal to Sidney, from Sidney via New Zealand, Tutuila, and the Sandwich Islands to San Francisco, and thence back to Japan. Apart from certain anomalies in volcanic districts and in the Tonga Deep, which is a vigorous earthquake center, the results correspond with what the theory of isostasy requires. The intensity of gravity over the ocean basins is everywhere normal. That is to say, there is the same mass beneath each part of the ocean surface; each such mass or column is composed of two parts, water above and rock below. The shorter the rock part, or the deeper the water, the heavier or denser the rock part must be, or, putting the relation in terms of isostatic balance, we may say the denser the rock the deeper the hollow in the earth's surface.

The confirmation of the isostatic law for the oceanic basins is of great importance in supporting the probability of a similar balance for the continents against the ocean basins and within the continental masses as well.

The present state of investigation into the subject of isostasy may reasonably be summed up as follows:

It is demonstrated that the larger masses of the outer earth, above a zone 120 kilometers deep, strive toward isostatic equilibrium. The condition of perfect balance has been most nearly attained within the ocean basins; the general balance of the continental plateaus and of the broad features of relief is at present also nearly perfect. If so, it is probable that the culmination of this mountain-building epoch is approaching, or is past.

Erosion is a process which destroys those elevations of the continental surface which appear to be essential to equilibrium, and which are probably a result of the effort toward it. The balance at any time is disturbed to the extent that erosion exceeds uplift. The long periods when, according to geologic evidence, lands have been low and featureless, have been periods of failure of equilibrium, periods of stress, when the low continental masses resisted uplift by virtue of rigidity.

Isostasy and rigidity both are conditions of the earth's mass. Their relative effects in the changes of stress in the earth vary with the state of uplift or erosion, and it is an interesting coincidence that intelligent research should investigate the condition during an epoch when equilibrium is most nearly complete and rigidity least severely stressed. But we may not overlook the fact that this condition is but a transient one.

If we apply these considerations to the question with which this review began, What are the foundations of the earth? We may answer: The foundations are solid rock, which is self-crushed to a depth of 120 kilometers, more or less, which is rendered sufficiently rigid by pressure to maintain its form during prolonged geologic periods with but very slight change, in spite of stresses occasioned by erosion of continental reliefs, but which is capable of movements that from time to time result in the gradual elevation of continents and the more vigorous uplifts of mountains through which isostatic equilibrium is restored.

TRANSPIRATION AND THE ASCENT OF SAP.[1]

By Henry H. Dixon, Sc. D., F. R. S.,
Professor of Botany in the University of Dublin.

The water of the transpiration stream enters at the roots, passes up the stem, and is given off from the leaves. It will be convenient to discuss the processes taking place in each of these organs separately, so far as they affect the stream, and then consider how these processes are correlated.

In regard to the exhalation of water vapor from the leaves, early experimenters have shown that cuticular transpiration is usually insignificant compared with diastomatic diffusion. The efficiency of diastomatic transpiration was first clearly explained by Brown and Escombe.[2]

The minute cross sections of the openings of stomata and the comparatively large area occupied by the practically impermeable cuticle made it difficult to understand how the observed quantities of water escape from the leaf. These authors showed, however, that an unexpected law governs the diffusion of water vapor through a number of minute perforations in an impermeable membrane. According to this law it follows that the amount which diffuses through the perforations is not only, as one would on first thoughts expect, proportional to the sum of their areas, but may vastly exceed this proportionality; and consequently the diffusion through a number of minute pores, like the stomata, will be much greater than through one large aperture having a cross section equal to the sum of the areas of the stomata.

In order to obtain a clearer idea of this remarkable result, we will consider in a general way the state of affairs around one stoma, so far as water vapor is concerned. At the level of the stoma the water vapor has a certain density—i. e., the water molecules are more or less crowded, depending on the state of saturation of the external space

[1] Reprinted, by permission, in abridged form, from Progressus Rei Botanicæ. Herausgegeben von der Association Internationale des Botanistes, redigiert von Dr. J. P. Lotsy. Dritter Band. Verlag von Gustav Fischer in Jena 1909.

[2] Brown and Escombe, Static Diffusion of Gases and Liquids in Relation to the Assimilation of Carbon and Translocation in Plants. Phil. Trans. Roy. Soc. Lond. B., vol. 193, pp. 223–292, 1900, of which an abstract appeared in the Proc. Roy. Soc., vol. 66, and in Ann. of Bot., vol. 14, Sept., 1900, pp. 537–542.

and the amount of water vapor in the stomatal chamber. At some distance outside the stoma the crowding depends solely on the state of saturation of the outside space. When the density outside is less than that at the level of the stoma there will be a gradient of density established extending outward from the stoma depending on the drift of water molecules from the more crowded level at the stoma to the less dense vapor outside. If we consider a point (a, fig. 1) immediately over the middle of the stoma, the water vapor there will have a certain density intermediate between that of the outside space and that in the stoma. All over the middle of the stoma places of the same density of water vapor will be approximately equally removed from the stoma, since these places lie in the general drift of water molecules from the stoma outward. Toward the margin of the opening, however, conditions are different. The molecules, jostling against each other as they issue from the stoma, tend to travel laterally as well as straight out from the stoma, so that the crowding at the margin is less intense than over the middle; hence a place (a') having the same density as (a) will be closer to the stoma. By connecting up the points of the same density or crowding we get a curve like a' a a', which represents the section of a layer (or shell) of equal density arching over the stoma. In the same way at a distance somewhat more removed from the stoma, there will be a layer of less density, and this layer will be at a greater distance from the middle of the stoma than it is from its margin. So we may imagine a series of layers or shells of diminishing density overarching each transpiring stoma, such are are represented in section in figure 1. Of course, in reality the higher density within grades insensibly into the lower density outside; this gradient of density, or crowding of the water molecules, is steeper near the margin than over the middle of the stoma. From this it follows that the flow of molecules outward is less obstructed on the margins. Consequently greater numbers escape there. In other words, the margin is more efficient in transmitting water vapor than the middle region of the stoma. As the size of an aperture is reduced the relation of its margin to its area is increased; for the value of $2\pi r$ does not decrease as fast as πr^2 when r is reduced. So, for a very small aperture like a stoma, the marginal diffusion is very large compared to that over its cross section, and hence the diffusion from a stoma is exceptionally efficient.

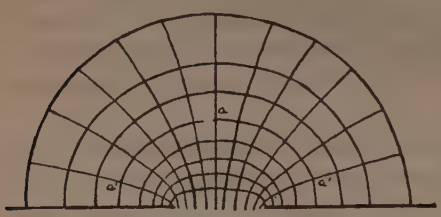


FIG. 1.

It will be readily seen that in order to maintain the efficiency of the marginal diffusion on the outside it is necessary that the diffusion streams from adjoining stomata should not interfere with one

another. This necessitates a certain interval between the openings. Brown and Escombe found that a membrane of 1 square centimeter area, perforated with 100 holes 0.38 millimeter diameter and 1 millimeter apart, transmitted by diffusion under identical conditions as much vapor as an open tube of the same cross section, although the total area of the holes was only 11.34 per cent of the cross section of the tube. When the distance between these holes is increased their efficiency in diffusion rapidly increases; thus, according to these authors, holes of the same diameter 6 millimeters apart on a membrane 1 square centimeter in size transmitted one-fifth as much as the open tube, while the total transmitting area was reduced by the interposition of the membrane to 0.3 per cent of the whole cross section. Figures like these will enable us to form some idea of the efficiency of a leaf. Brown and Escombe,[1] taking as an example a leaf of Helianthus in which the average area of the stomatal opening is 908×10^{-7} square millimeters (= a circle 0.0107 millimeter diameter) and the spacing of the apertures 8 to 10 diameters, and allowing for the resistance of the stomatal tube (which leads through the epidermis), found that the amount of diffusion from a square meter could be as much as 1,730 cubic centimeters of water per hour, when the state of saturation of the surrounding space was one-fourth of that of the spaces within the leaf. The greatest amount of transpiration observed in the same time was 276 cubic centimeters. This clearly shows that it is not the resistance offered by the stomata to diffusion which puts the limit on transpiration in still air. * * *

The considerations just stated show that the stomata when open provide ample means for the exit of water vapor from the intercellular spaces of the leaves. We will now proceed to inquire into the physical conditions under which the water vapor enters these spaces.

As long as the spaces are not saturated there will be a flux of water molecules from the adjoining moist surfaces into the spaces, since the vapor pressure of the water imbibed by the cell membranes of the mesophyll cells there exceeds the vapor pressure in the adjoining intercellular spaces. How is this loss made good? On first thoughts it might appear impossible for pure water to pass easily from the cells which possess a considerable osmotic pressure within their more or less perfect semipermeable membranes, and we know experimentally it is not possible to extract water from them by osmosis unless the pressure of their solutions is balanced by an equal external osmotic pressure. This balancing pressure may amount to several atmospheres.[2] While this is true in the case of abstracting

[1] Brown and Escombe, loc. cit. Phil. Trans. Roy. Soc. Lond., p. 279.

[2] H. H. Dixon, Rôle of Osmosis in Transpiration. Proc. Roy. Irish Acad., ser. 3, vol. 3, 1896, p. 774, and Notes from the Botanical School, Trinity College, Dublin, No. 2, p. 42; Idem, A Transpiration Model. Proc. Roy. Dub. Soc., vol. 10, N. S., 1903, p. 119, and Notes from the Botanical School, Trin. Coll., Dub., No. 6, p. 222.

water from the cell so as to diminish its total water content, quite a small difference of pressure will cause water to move across the cell when it is distended to its maximum with water. The osmotic pressure of the cell then acts simply as a force pushing the protoplasmic lining against its walls, while the water on one side of the cell is free to move across to the other side except for the resistance it experiences in passing through the cell walls and protoplasm. In the present instance this force is the difference of vapor pressure existing on the inner and the outer, or evaporating, side of the mesophyll cell. It might happen that this difference would be sufficient to almost keep the wall on the evaporating side flooded with water, and then evaporation into the intercellular space would take place as if from a free liquid surface; or, if evaporation proceeded more rapidly, the liquid surface might retreat into the substance of the evaporating wall. Then the capillary or imbibitional properties of the wall would exert a force drawing the water through the cell and bringing it to the surface of evaporation. The retreat of the water surface would proceed till the capillary forces so produced could bring forward water as fast as it evaporated from the surface and a steady state were arrived at.

According to this point of view the submicroscopic spaces occupied by the imbibed water in the cell walls are regarded as intensely minute capillary passages. When water is lost, the surface of that which remains behind retreats in the form of innumerable menisci into these spaces. The capillary forces intensify as these menisci increase the sharpness of their curvature, and may attain an extremely high value owing to the fineness of the texture of the cellulose. The contraction of cellulose on drying, involving the reduction of these passages, enhances this effect so that the capillary traction drawing the water from the cell within may become enormous.

If the supply coming into the cells were small compared with the evaporation, it might be that the steady state would not be attained until the capillary forces, bringing water forward as it evaporated, had actually reduced the volume of water in the cell and consequently reduced its turgor. Under these conditions we would have the capillary forces of the outer cell wall pitted against the osmotic solutions in the cell itself, and, if exerting a superior force, drawing water into and across the cell, now somewhat diminished in size and containing a more concentrated solution; but, all the same, the flow across the cell is determined by the difference of vapor pressure on its opposite sides. * * *

The most vexed problem of the ascent of sap is how the water rises in the stem to fill the tracheæ of the leaves.

Botanists have sought solutions of this problem in two directions, viz: (1) In the energy transformations taking place in the living

parts of the stem, namely, in the cells of the wood and of the medullary rays, acting to raise the water, and (2) in the energy transmitted and applied by means of the physical properties of the conducting tracts and of the water stream itself, not necessarily involving any special vital activity on the part of the cells of the stem. Those hypotheses which belong to the first category may be distinguished as the vital and those of the second as the physical theories of the ascent of sap.

PHYSICAL THEORIES.

The vital hypotheses of the ascent of the transpiration current take no direct account of the inflow of energy at the leaves. The entire sap-lifting force is applied in the stem. This appears to hold good for all the vital hypotheses with the exception of that of Ewart, who admits that possibly some of the energy needed to raise the water may be directly transmitted downward from the leaves to the stream in the stem. Of course ultimately the energy assumed by the vital hypotheses to be expended in the stem is derivable from the energetic substances formed in the leaves during photosynthesis, and afterwards distributed to the cells of the stem. * * *

In 1894 Dr. J. Joly and the author published the first account of their cohesion theory of the ascent of sap. In the work leading up to our theory we naturally submitted the theories of previous investigators, so far as we were acquainted with them, to full consideration and experimental examination. In addition to these we subjected various other hypotheses formed by ourselves to investigation.[1] As these investigations naturally lead us up to the cohesion theory, it may be permissible to briefly outline them here.

In the first place it seemed possible that perhaps gravitation itself might furnish the lifting force of the upward moving water. This, at first, seems paradoxical. Suppose the dilute sap in the leaves to be concentrated by evaporation and by the addition of carbohydrates. The denser fluid thus produced and passed into the tracheids would settle downward. As it passed down it would displace upward the less concentrated solutions entering at the root. An accumulation of the denser material in the lower part of the tree may be supposed to be prevented by the abstraction of materials from the concentrated sap all the way down. In this way it is secured that the ascending "raw" sap is just overbalanced by the denser descending column, and the very dilute solutions brought into the root might in this way be raised to any height. A model illustrating the hypothesis is easily set up. A tube, say, 1 millimeter

[1] H. H. Dixon: On the physics of the transpiration current. Notes from the Botanical School, Trinity College, Dublin, 2, 1897, p. 4.

bore and closed at the lower end, is filled with a solution of a dye, e. g., fuchsin, and set upright. A small funnel containing a denser salt solution is attached to its upper end. The heavy solution immediately begins to gravitate downward, and in doing so displaces an equal volume of the lighter fluid upward. The rise may be noted by the passage of the colored fluid upward in the funnel.

There is no doubt that this mechanism could work in uninjured plants whose roots continued to pass comparatively pure water into the conducting tracts, provided there were an arrangement to prevent the mixing of the descending and ascending fluids. In the plant, we may suppose, the column is not supported below as in the model, but is held up by the capillary forces of the imbibed cell walls. This would explain the presence of reduced air pressure in the cavities of some of the wood tracheæ, which would be impossible if the water surrounding them were in compression. But, however promising for a time, the theory had to be given up. The mingling of the dilute ascending solutions with the concentrated descending fluids which inevitably takes place in narrow tubes, would certainly destroy this gravitational action in the tracheæ of plants, and there is no evidence whatever of isolated upward and downward currents.

Quincke's theory[1] (which suggested itself independently to us), viz, that the water is drawn up in a tensile state over the surfaces of the walls of the conducting tracheæ in the form of a thin film, had also to be laid aside. Not, however, by reason of Sachs's objection, who rejected it because there are not continuous tubes in plants. In reality this objection is quite invalid, since the water films may be regarded as continuous through the imbibed material of the transverse and oblique walls. Nevertheless the theory had to be abandoned, since, as we shall see later, such a film of water unsupported on one side, if exposed to tension, infallibly draws out thinner and thinner until it breaks across and leaves no water on the surface.

A modification of this theory, combining it with the Unger-Sachs imbibition theory, then suggested itself. In order to escape the inevitable thinning out of the unsupported water films, we assumed with Sachs, that the moving water is located in the substance of the walls, and that the surface-tension forces developed at the surface of the fine-textured substance of the wall prevent the water from drawing out thinner and thinner. Thus the tension generated at the leaves is transmitted downward through the imbibed water in the walls. This theory has undoubted advantages over the imbibition hypothesis. It replaces the diffusion flow by a movement under great tensions, and so the rate of transmission may be in-

[1] J. von Sachs, Lectures on the Physiology of Plants. Trans. by H. Marshall Ward, Oxford, 1887, p. 238.

creased proportionately to the increased tension. But it is open to many of the objections which overthrew the imbibition hypothesis, viz, the lumina are known to transmit the major part of the current, and it seems improbable, even where we can invoke such great forces as the tensile strength of water, that they could suffice to drag an adequate water supply through the fine-grained cell walls. Yet we were able to show by experiment that even when the lumina are rendered impassable for water, some small amount of water is transmitted in the walls by this process.

When we found ourselves compelled to give up these hypotheses, the one, as assuming conditions inimical to the transmission of tension in the water, and the other, because it did not agree with the ascertained fact that the water moved in the lumina, it was an easy transition to arrive at the conclusion that the water passed up in the lumina in a state of tension. How, in the lumina of the conducting wood, the necessary conditions for the production of tension are fulfilled, we shall now proceed to enquire.

Even in textbooks of physics the cohesion of liquids is seldom alluded to, and the conditions necessary to produce a state in which liquids may transmit a tensile stress are not adequately treated.

Donny in 1846 showed that it was possible for a column of sulphuric acid 1.255 millimeters high to hang in a vertical tube closed at its upper end, when atmospheric pressure was not allowed to press the liquid upward from below. He compares the phenomenon to the well-known experience that the mercury of a barometer may be retained above the actual barometric height if the tube, filled by inclining it, is raised gradually to a vertical position. He further states that this phenomenon has been explained by Laplace as being due to the cohesion of the mercury and to its adhesion to the glass. * * *

Berthelot[1] a few years afterwards succeeded in showing directly that water has a very considerable cohesive strength and, under proper conditions, can sustain a very great tensile stress. His procedure was as follows: He filled a strong capillary tube, which was sealed at one end and drawn to a fine point at the other, with water at a temperature of 28° or 30° C. He allowed it to cool to 18°, and, as it cooled, to draw in air. Then the fine-drawn end was sealed. The tube was now heated to 28° or over, and the air forced into solution in the water, which now occupied the whole of the internal space of the tube. On cooling to 18° or lower it was found that the liquid continued to occupy the entire space enclosed by the tube and preserved in this way the same density from 28° to 18°. The dilatation needed to effect this is very large, viz, for water one four-hundred-and-twentieth of its volume at 18° C. To produce a similar

[1] M. Berthelot, Sur quelques phénomènes de dilatation forcée des liquides. Ann. Chim. et de Phys., vol. 30, 1850, pp. 232 et seq.

effect in the opposite sense would require a pressure of about 50 atmospheres. The experiment shows that neither the adhesion to the glass nor the cohesion of the water is less than 50 atmospheres. Berthelot's experiment has been variously misquoted (1) with regard to the dilatation observed and (2) as to the effect of dissolved air on the tensile strength of water. * * *

Although a priori there seemed no reason to suspect that the presence of dissolved air would weaken the tensile strength of water, Dr. Joly and the author[1] considered it necessary to investigate the point specially. We used a cylindrical glass vessel with rounded ends and provided at one end with a narrow tubulure. This vessel was very carefully cleansed by washing it internally successively with caustic potash solution, dilute acid, and distilled water. Half filled with water, it was boiled for some time to make sure that the walls were thoroughly wetted; then it was almost completely filled with water which had been previously boiled to get rid of undissolved air and thoroughly to wet all dust particles which might have been contained in the liquid. By subsequent exposure to air this water was allowed to become saturated with dissolved air. During exposure care was taken to shield the water from dust, which might not have been completely wetted or which might have introduced small bubbles. To fill the vessel a small quantity of water in it was raised to ebullition, and, while steam was issuing from the attenuated tubulure, the latter was submerged in the dust-free water. As the steam within condensed and the vessel cooled, the latter became completely filled with water. A small bubble was then introduced and the vessel was closed by sealing off the tubulure.

If the vessel was then cautiously heated, the water expanded more than its glass envelope and the air bubble was compressed. The bubble became smaller and smaller as the temperature rose and the contained gas was forced into solution. When the bubble had reached very small dimensions and was about to disappear great care had to be exercised in the further application of heat; for if the water expanded too much and strained the glass beyond its elastic limit, the whole experiment was rendered abortive by the breaking of the glass. But if the heating process had been carried on successfully and all the air had been dissolved so that the water had been made to completely fill the vessel without breaking it, heating was stopped and the water ceased to expand.

At this moment the water in the vessel was either in compression, being constrained by a tension in the glass walls, or it was quite unconstrained, just exactly filling the envelope, and neither suffering compression nor causing tension in the walls. As soon as cooling

[1] H. H. Dixon and J. Joly, On the Ascent of Sap. Phil. Trans. Roy Soc. London, vol. 186 (1895), B, pp. 568 et seq.

began, the water and the glass commenced to contract. The coefficient of expansion for heat of water being greater than that of glass, the water tended to contract more. This contraction, however, was resisted by its adhesion to the glass and its own cohesion, and consequently a stress or tension, which kept it sufficiently dilated to fill the glass, was set up. As cooling proceeded the tension grew greater and greater, till at last either the adhesion or cohesion was overcome and a break appeared either between the water and the glass or in the substance of the water itself. The appearance of this rupture was signalized by a sharp click, and a bubble sprang into existence in the water. The bubble thus produced rapidly augmented in size as the water, now relieved from the stretching forces, assumed a volume corresponding to its temperature at the moment. Bubbles appear around the original bubble and pass into it.

By estimating the amount of deformation[1] of the glass envelope when strained by the contracting water, and by determining experimentally the pressure needed to produce the same deformation, the amount of the tensile stress which was sustained by the water before rupture was determined. In an experiment, carried out in the manner just described, water was subjected to a tension or pull equivalent to 7.5 atmospheres before its cohesion was overcome.

As was noticed this method of showing the cohesive property of water is precarious—the slighest overheating is liable to burst the glass vessel containing the water. It is convenient therefore to have a more simple method of demonstrating this property, which may be repeated as often as is desired without risk. The following method fulfills these conditions.[2]

The vessel in which the liquid is to be inclosed is a J-shaped glass tube about 1 centimeter in diameter (see fig. 2). The long limb of the J is about 90 centimeters while the shorter one is about 20 centimeters long. On the shorter limb there is a bulb with a capacity of about 60 cubic centimeters. The shorter limb is continued beyond the bulb as a narrow tube drawn out to a point. The whole tube is carefully washed out in the manner described in the preceding experiment and about 100 cubic centimeters of repeatedly boiled water is introduced into it. In order to be certain that the glass is thoroughly wetted, and also to make sure that the water is in perfect contact with any dust particles contained in it, the liquid is again repeatedly boiled after introduction into the tube. Before sealing off the fine tube the whole of the space unoccupied by the liquid is filled with steam by bringing the water to ebullition, and, when the

[1] H. H. Dixon and J. Joly, On the Ascent of Sap. Phil. Trans. Roy. Soc. London, vol. 186 (1895), B, p. 569.

[2] H. H. Dixon, Physics of the Transpiration Current. Notes from the Botanical School, Trinity College, Dublin, No. 2, 1897, p. 5.

steam has expelled the air and is issuing through the narrow tube the latter is sealed off. When the whole has cooled it will be found that the J tube acts as a water hammer, i. e., if, by inclining the tube the water is made to travel from end to end, its concussion makes a metallic ring. This is owing to the fact that very little air has been included when the tube was sealed, and water vapor at normal temperatures is unable to act as an elastic pad in the same way as air at normal atmospheric pressure would. The clicking metallic ring then may be taken as an indication that the gas pressure within the tube is very slight. Care must indeed be taken not to let the concussion become too violent, as in that way the tube may be easily shattered.

If now, by carefully inclining the tube, the long limb is completely filled with water (fig. 2 B) and all the bubbles are chased out of that limb by holding the bent end uppermost, so that no breaks, even the most minute, remain, we shall find, on inverting the tube and bringing the bent end under, that the water remains in the long limb and does not under the force of gravity take up the lowest possible level in both limbs (fig. 2 C). From the level in the two limbs it is evident that the hydrostatic pressure of the shorter column can not possibly balance the pressure of the column in the longer limb. The one is about 85 centimeters higher than the other. The water in this case, like the sulphuric acid in Donny's experiment, hangs in the tube. The liquid in the long limb is in contact with the glass all over, and, since it wets it perfectly, it adheres to it. To the film of water adhering to the glass the rest of the water coheres, and this cohesion is much more than able to sustain the weight of the column of water which is counterbalanced by no other upholding force. In this way the lower part of the water in the longer limb of the tube transmits through the upper part a stress to the glass equivalent to its gravitational pull.

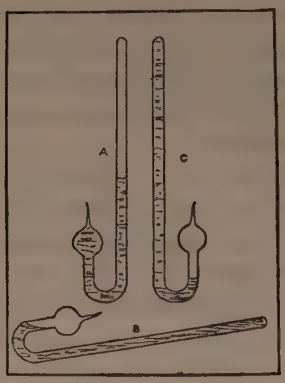


FIG. 2.

The reality of this pull becomes all the more striking when, by destroying the cohesion at one spot, a rupture is started. This rupture, which may be at first invisibly small, rapidly spreads across the whole column. The rupture may usually be started by a sharp knock administered to the side of the longer limb; but, when the cohesion is very perfect, to produce a rupture may require a shock so violent as to be liable to shatter the tube. When the rupture is started, the lower part tears suddenly away from the upper part of the column and falls into the bend of the tube. The upper part follows it more slowly, trickling down the inside of the tube, and all the water comes to occupy a position in the lower part of the tube (fig. 2 A).

It is instructive to note how the cohesion of the water in these experiments is overcome. The rupture starts as an extremely small space or discontinuity in the water. Immediately surface tension forces develop at the surface of this bubble. At its inception, being extremely small, these forces are very great, but if the bubble enlarges, the surface tension forces tending to close it rapidly diminish. In our experiments the forces tending to open it are (1) the momentum of the water conferred on it by the shock, and (2) the gravitational pull giving rise to the tension in the liquid. We may neglect the vapor pressure of the bubble, as it is balanced by the vapor in the other limb. If the break opened by the shock is so small that its surface tension forces can withstand the tension in the liquid the bubble will close again; but if once the bubble formed is so large that its surface tension is overcome by the tension of the liquid, an unstable condition is entered on, and the bubble is continually enlarged till the tension of the liquid is nil. It is, however, evident that if at any moment we could confine the bubble and prevent it from enlarging, the liquid would again pass into a state of tension due to the weight of the lower parts.

Quite recently the author[1] has been able, by using Berthelot's method, to show that the cohesion of water amounts at least to 150 atmospheres and that water, even when subjected to a tension of this magnitude, refuses to be severed from the walls of the conducting tracts of plants. The water used in these experiments was saturated with air and contained in it pieces of the conducting tracts of plants. The range of temperature over which this cohesion was exhibited lay between 25° and 80° C.

The theory of the ascent of sap, which Dr. Joly and the author advocate, assumes that the water in the conducting tracts of high trees hangs there by virtue of its cohesion just in the same way as the water hangs in the J tube. The adhesion of water to the walls of the tracheæ may be shown to be very great. Thus, if a fresh piece of wood from the conducting tracts is inclosed in a vessel filled with water in a state of tension, it will be found that in every case rupture will occur at the surface of the glass rather than at the walls of the tracheæ. The adhesion of water to the walls of the conducting tubes is thus probably always greater than the adhesion of water to glass. This is quite to be expected, if we take into account the manner in which water permeates the substance of the walls of the tracheæ when it is brought into contact with it.

The teaching of all these experiments is obviously that water under suitable conditions can transmit a pull just like a rigid solid. In the liquid, however, the stress is hydrostatic, and, like hydrostatic

[1] H. H. Dixon, Note on tensile Strength of Water: Proc. Roy. Dublin Soc., 1909, and Notes from the Botanical School, Trinity College, Dublin, vol. 2, No. 1. 1909.

pressure, is transmitted equally in all directions. It is not sustained, consequently, by a single point, but affects the whole internal wetted surface of the containing vessel. In another particular the stressed liquid differs greatly from the stressed solid. It is much more unstable. A small flaw (i. e., a bubble) in the tensile liquid rapidly spreads and almost instantaneously severs the whole column; it matters not how large the cross section of the unbroken part may be, a comparatively feeble tension will tear it across. In the solid—a metal wire, for example—on the other hand, if the cross section of the unbroken part is sufficient, a small discontinuity in its substance is immaterial, and the stress may be successfully resisted by the intact part. This difference in the behavior of the two forms of matter when submitted to a stretching force is to be referred to the fact that the particles of a liquid are perfectly mobile and are free to move round each other without being opposed by any sensible internal forces, whereas in solids there is a great opposition to the relative motion of the parts. To this property solids owe their rigidity. In fact, in tension experiments the liquid becomes capable of sustaining[1] and transmitting tensile stresses only when it is adhering completely to a rigid envelope which confers on the liquid a pseudo-rigidity. The state of tension then persists because the stretching forces act solely against the cohesive properties of the liquid (i. e., in an endeavor to separate the water molecules from one another—a separation which a liquid is able to withstand as well as a solid). If, however, the liquid is free to change its shape, not adhering to any rigid envelope, the smallest forces, whether of compression or of tension, spend themselves in leading to a readjustment of form to which the liquid owing to its mobility, readily submits, and no stress is produced. On the other hand, if a pull is exerted on a liquid which thoroughly wets and adheres to the internal surface of a rigid vessel and if there are no bubbles or discontinuities in the liquid, a state of tension inevitably supervenes.

We have seen that the evaporation taking place from the outer surfaces of the mesophyll cells is continually abstracting water from the tracheæ of the leaf. It is a matter of common observation that these tracheæ are constantly filled with water and they inclose no bubbles. Experiments on pieces of the conducting tracts of plants, as described above, show that the adhesion between their walls and water is as great as, and probably much greater than, the adhesion between glass and water. Hence, if water is given off from the cells more rapidly than lifting forces raise it in the tracheæ, the water in the latter must inevitably fall into a state of tension.

Apart from root pressure, investigation has shown that the only force from below which is effective in raising water in plants is the

[1] H. H. Dixon, Physics of the Transpiration Current, loc. cit.

pressure exerted by the atmosphere. The amounts of water forced up by root pressure are insignificant compared with the losses due to transpiration. Atmospheric pressure can supply the evaporating cells at most only up to a level of about 10.3 meters. When allowance is made for the resistance opposed by the conducting tracts to the motion of water in them, we must conclude that the supply of water raised by these two forces to a height of 10 meters above the roots must be exceedingly small. It follows that the water in the tracheæ above this level is at all times in tension, and, in times of vigorous transpiration, whenever the loss can not be made good by the lifting pressure of the atmosphere, the water in the tracheæ of leaves at lower levels also is in a tensile state. This tensile state is no less inevitable at the top of the column of water unsupported at the base, such as is found in a high tree, than is the state of compression at the bottom of a deep vessel filled with water. The former is caused by the weight acting against the cohesive forces of the water, while the latter is necessitated by the weight acting against the resistance of the water to crushing.

Owing to the permeable nature of the walls, the water in one trachea is continuous with that in its neighbors, and consequently the tension in one is transmitted to the water in adjacent tracheæ. Thus the tension applied at the mesophyll cell surfaces is transmitted downwards, through the water in the tracheæ of the leaf and of the petiole, to the water in those of the stem.

While air bubbles are found extremely rarely in the tracheæ of the vascular bundles of the leaf, investigators seem agreed that they are of common occurrence in the conducting tissues of the stem. It is evident that in the tensile water in plants these bubbles will behave exactly in the same way as we have seen bubbles behave in the experiments on tensile fluids. If they are sufficiently minute, they will have a very small radius of curvature, and the surface tension forces preventing them from enlarging will be correspondingly great. When these forces balance, or are greater than, the tension in the water, the tension will be transmitted past the bubbles, and if the bubbles adhere to the walls of the tracheæ, the tensile stream will be drawn past them. Kamerling[1] has shown that a bubble having a radius of 0.01 millimeter is in equilibrium with a pull equal to the hydrostatic head of 1.65 meters. While one having a radius of 0.001 millimeter$=1\ \mu$ could resist the tension exerted by a column of 16.5 meters of water. Bubbles having a radius of $1\ \mu$ would just be visible with the highest dry objectives commonly in use, their diameter being about one-fifth of the diameter of the lumen of the finest tracheids of the pine. Bubbles of this minute size are almost never observed in the tracheæ of plants. In fact, the methods of prepara-

[1] Z. Kamerling, Oberflächenspannung und Cohäsion. Bot. Centralbl., 73. 1898.

tion, involving as they do the relief of the existing tension, or even the exposure to atmospheric pressure, would cause bubbles of this magnitude to disappear. A tension anything greater than the pull exerted by a column of water 1.65 meters will overcome the surface tension of bubbles having a diameter of 0.02 millimeter, and they will tend to expand indefinitely under its action. Tensions as great as this must frequently occur in plants. On first thoughts it might appear, then, that one bubble having a diameter of 0.02 millimeter or more would destroy the possibility of tension in the water of the conducting tracts. A moment's consideration, however, will show that the structure of these tracts sets a limit to the enlargement of the bubble. In the conducting tracts after the formation of a bubble the sequence of events will be as follows: The water around the bubble is drawn away by the tension and the surface of the bubble comes to rest against the wall of the trachea in which it has developed. The retreating surface is held by the wall, and as more water is drawn away the bubble can enlarge only longitudinally. At this period the surface tension of the spherical bubble is replaced by the capillary forces of the tubular trachea, and, the capillary forces developed in these tubes being insufficient to withstand the tension, the bubble gradually pulls out till it completely fills the trachea. When this stage is reached the bubble can enlarge no more; its surface is restrained on all sides by the walls of the trachea, which, as is well known, though very permeable to water, are so fine grained that their capillary or imbibitional forces are enormous and hold the surface of the water, limiting the bubble close to their inner surface. Surrounded thus by the imbibed and rigid wall of the trachea the bubble becomes just like a wetted solid or rigid body in the tensile current. No doubt it diminishes the effective cross section of the flow, but, owing to the fact that the conducting tracts are subdivided into such numbers of minute compartments, the development of even a large number of bubbles is unable to wreck the stability of the tensile column of water in the wood.

The state of affairs in the conducting tissues is illustrated in figure 3. For the sake of simplicity a longitudinal section of a conifer's wood is represented. The shaded tracheids are supposed to be filled with water, while the light spaces indicate those containing air bubbles, which have been expanded by the tension of the transpiration stream till they completely fill the tracheids in which the bubbles occur. It is evident that even when a large number of tracheids are blocked with air the water column in the wood is not broken, but is drawn around the bubbles inclosed in and rendered harmless by the walls of the tracheids. In the figure for example 50 per cent of the tracheids contain bubbles, and yet a considerable volume of water might be drawn up in the remaining tubes. The imbibitional proper-

ties of the walls of contiguous water-filled tracheids render the water throughout the stem continuous. Consequently the stress developed above is transmitted around the air bubbles and draws the stream past them, to use Schwendener's figure, like islands in a river. Hence it is evident that it would be impossible to sever the continuity of the water in the conducting tracts, i. e., to prevent evaporation above from transmitting a pull to the water in the roots unless tracheæ containing bubbles were to form in some place an unbroken diaphragm across the conducting tissues of the stem.

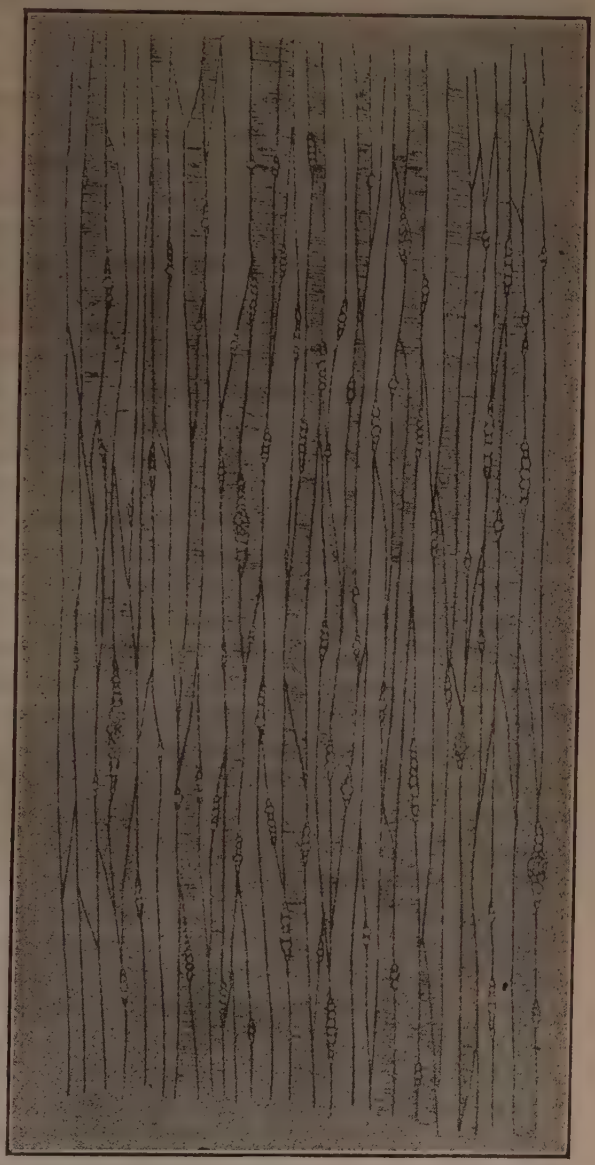


FIG. 3.

From this examination it appears that unless an exceedingly large number of the conducting tubes contain air and are arranged in a special manner there is no likelihood of the tensile column being broken. On the other hand, the amount of water transmitted in the stream will be affected by the number of tracheæ which contain bubbles and which are consequently put out of action in the transmission of water drawn upwards under tension. * * * Although our knowledge as to the actual proportion of tracheæ containing bubbles during transpiration is very unsatis-

factory, yet we have no evidence that the continuity of the whole water column is ever during transpiration interrupted in plants.

Here it will be interesting to consider the structure of the conducting tracts and to see how far their details bear out the theory of the tensile sap.

The salient feature of this structure is the subdivision of the waterways by an immense number of longitudinal and transverse partitions into minute compartments—the vessels and tracheids. For a system the function of which is to conduct fluids, this is evidently a most unexpected configuration. It is true that the partitions are permeable to water; but when a considerable distance is to be traversed, the sum of the resistances opposed by the walls to the flow is not inappreciable. This becomes clear from the experiments of Böhm,[1] Elfving,[2] and Strasburger,[3] comparing the conductivity of wood in tangential and longitudinal directions. From them is seen that the pressure required to force water in a tangential direction is immensely greater than that needed to urge it longitudinally in the wood, although in both cases the water is free to move through the pits. In the tangential direction, however, in the same distance the number of walls traversed may be hundreds of times greater than in the longitudinal path. It is evident that the persistence of the walls in the development of the water conduits of plants—introducing, as they are shown to do, an immense resistance to flow—is inexplicable on any view which regards the water as being forced through the stem. Viewed, however, in the light of the tension hypothesis this structure becomes a most beautiful adaptation to confer stability on the tensilely stressed transpiration stream, and one which transforms the water, despite its mobility, into a substance which is stable while sustaining very great stresses, just as if it were a rigid body. True, the tensile stream experiences the resistance opposed by the numerous walls, but the presence of the partitions, conferring, in the manner just pointed out, a new property on the water, renders available such an enormous source of energy at the evaporating surfaces in the leaves for the lifting of the sap, that the amount of energy which is spent in overcoming the resistance opposed by the walls is relatively insignificant.

The elongated form of the conducting elements secures that the resistance shall be small consistently with the stability of the water;

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[1] J. Böhm, De la cause du mouvement de l'eau et de la faible pression de l'air dans les Plantes. Ann. d. Sci. Nat. Bot., XII, 1881, p. 233. Idem, Ueber die Ursache der Wasserbewegung und der geringeren Lufttension in transpirirenden Pflanzen. Bot. Ztg., 49. 1881.

[2] Fr. Elfving, Ueber die Wasserleitung im Holz. Bot. Ztg., 42. 1882.

[3] Ed. Strasburger, Ueber den Bau und Verrichtungen der Leitungsbahnen in den Pflanzen. Jena, 1891, p. 739.

for, of course, if the tension is great, a bubble in a long tube renders a larger portion of the conducting tissues useless than one confined in a short vessel; but, on the other hand, when the long tube is completely filled it transmits more readily than if it were subdivided into a number of tracheids. Hence we may regard the tissue formed of long vessels as the path of the most rapid part of the transpiration current when the plant has an abundant supply of water, while the tracheids transmit the slowly moving water and continue in function even when supplies are very limited. It is also evident that the small cross section of the tubes, though also introducing resistance, is most essential. In this way each bubble which is formed occupies only an infinitesimal part of the cross section of the whole water current.

The structure of the walls themselves is also in complete harmony with the tension hypothesis, and finds its most natural explanation viewed in the light of that hypothesis.

It has long been recognized that the thickenings found on the walls of the tracheæ, viz, the internal supports in the form of annuli, spirals, and networks, are of such a nature that they are preeminently suited to resist crushing forces.[1] Such strengthenings are quite meaningless from the point of view of the imbibition and the various vital hypotheses; and even according to those views which regarded the sap pressed upwards by gas or atmospheric pressure they are needlessly strong. For it has been shown that it is impossible to crush the tubes of a leaf by an external pressure amounting to 30 atmospheres,[2] when, according to the theories just alluded to, they would be exposed to one atmosphere at most. The presence of these thickenings in the tracheæ of the leaves forbids us accepting Elfving's view that they protect the tubes from the pressure of the growing tissues. If needlessly bulky they are disadvantageous because they produce friction and introduce turbulent motion into the upward stream. Ewart finds[3] that owing to the presence of these thickenings and to the transverse walls, the flow of water through the capillary tubes of plants (viz, tracheæ) is only about half what we would expect to find calculating the flow by Poiseuille's formula. Consequently for ordinary methods of transference assumed in earlier theories the tracheæ of the plant can not be regarded as very efficient. For the trans-

[1] Fr. Elfving, Ueber die Wasserleitung im Holz. Bot. Ztg., 42. 1882.

[2] As appears from the fact that water is pressed backwards from the leaf cells into the branches by pressures of about this magnitude. Cf. Report of a Discussion on the Ascent of Waters in Trees. Ann. of Bot., vol. 10, Dec., 1898, p. 655. H. H. Dixon On the Physics of the Transpiration Current. Notes from the Botanical School, Trinity College, Dublin, No. 2, 1897, p. 28.

[3] A. J. Ewart, On the Ascent of Water in Trees (First Paper). Phil. Trans. Roy. Soc. Lond., vol. 198, (1905), B, p. 50.

mission and stability of a tensile stream, however, these thickenings are essential. And their strength, so far from being superfluous, is probably often tested severely in times when the transpiration removes large quantities of water and so develops high tensions in the sap. The whole wall is not thickened uniformly because the permeability of the thinner parts is essential. The thickenings confer on the thin walls the rigidity necessary to support the tensile stresses in the sap.

It is interesting to find that we often have indications that the unsupported wall would not in itself have sufficient rigidity to bear the crushing forces it is exposed to. These indications are particularly frequent in the protoxylem.[1] Here commonly, when elongation has widely separated the rings and spirals, the thin part of the walls of the vessels is drawn in as a constriction between the spiral or annular supports, and often the whole vessel is collapsed if the supports have become too oblique. That this is not due to the pressure exerted by the growth of the surrounding tissues follows from the fact that these instances are most frequently found in leaves.

The most perfect adaptation to secure the advantages of ease of flow without seriously reducing the rigidity of the tracheæ is to be found in the most general of all the wall structures, viz, the bordered pit. The membrane and torus of each bordered pit in the conducting tracheæ is able to take up three positions—a median position, symmetrically dividing each domed chamber of the pit from the other, and two aspirated or lateral positions. The median position is naturally assumed by the more or less tightly stretched membrane when it is not acted upon by lateral forces. In the aspirated positions the membrane is deflected against one dome or the other and the torus lies over and fills the opening into the dome. The membranes of pits in the common wall separating two adjacent tracheæ filled with water naturally take up the median position. Pappenheim[2] found that an immence rush of water through the pit was needed to deflect the membrane to one side. A moderate flow does not disturb it from its median position. The reason for this is to be found in the fact that the membrane around the torus is very permeable to water, and consequently water moving at a moderate speed passes through it easily without displacing it.

The normal transpiration current never possesses the velocities which Pappenheim found were necessary to deflect the membrane, and, of course, hydrostatic tension in the liquid on each side of the

[1] H. H. Dixon, Physics of the Transpiration Current. Notes from the Botanical School, Trinity College, Dublin, No. 2, 1897, p. 14.

[2] K. Pappenheim, Zur Frage der Verschlussfähigkeit der Hoftüpfel im Splintholze der Coniferen. Ber. d. Deutsch. Bot. Gesell., vol. 7, 1889, pp. 2 et seq.

membrane will not tend to displace it. Hence it is that the tensile transpiration current passing from one trachea to another through the bordered pits experiences only the minimal resistance of the porous and thin membrane. But the very delicacy and porosity of the membrane render it unsuitable for sustaining any severe stress, and so we find when a bubble develops in a trachea and is gradually distended by the tension in the liquid, or by a difference of gas pressure, till it fills the trachea, the membranes of the pits in the walls of the trachea become aspirated away from the bubble, and the membrane is supported by the dome, while the torus lies over the perforation in the latter like a washer or plug. (See fig. 4.) In this position of the membrane the tension of the water and the gas pressure are withstood, not by the thin and delicate membrane, but by the surface of the water, supported by the denser and more rigid material of the wall and of the torus, while the delicate membrane is shielded from all stress.

Thus, from the standpoint of the tension hypothesis, we regard the bordered pits as mechanisms to render the walls as permeable as possible to continuous water streams, while, when conditions require, they provide, by an automatic change, a rigid support to the tensile sap and oppose an impermeable barrier to undissolved gas. * * *

THE SACRED EAR-FLOWER OF THE AZTECS: XOCHINACAZTLI.

[With 1 plate.]

By William Edwin Safford.

Among the marvels of the New World which excited the admiration of the Spanish conquistadores were the parks and gardens of the Aztec Emperor and his nobles. Cortez, in his official reports to Charles V, described them at length.

At Iztapalapan, on a peninsula between Lake Chalco and Lake Tezcuco, there was a park which covered a very large area, laid out in squares, with the intersecting paths bordered by vine-covered trellises and aromatic shrubs which filled the air with perfume. Many of the trees and shrubs had been brought from great distances, and the gardens were arranged in regular plots, irrigated by ditches. There were aviaries filled with birds, remarkable for their brilliant plumage and their songs. There was a great basin, or reservoir of stone, stocked with fishes of many kinds. This is described as having a circumference of 1,600 paces, and around it there was a stone pavement wide enough for four persons to walk abreast. Its sides were sculptured with curious designs, and a flight of steps led down to the water, which fed the irrigating ditches and was the source of beautiful fountains. So elaborate and magnificent were the gardens described by the conquistadores that we might well doubt the truth of their assertions, were the evidence not attested by many witnesses.

In the capital city itself the Emperor had established the botanical garden of Tetzcotzinco, of which there still remain a few vestiges. After having gathered together all the plants and animals which could endure the climate, the Emperor caused the pictures of others to be painted upon the walls of his residence, so that the whole of the fauna and flora of Anahuac might be represented.

A few leagues south of the City of Mexico, in the direction of the modern city of Cuernavaca, was the wonderful garden of Huaxtepec, which survived the conquest, and to which Hernandez frequently re-

fers in his great work. Here were collected trees, shrubs, and herbaceous plants, native and exotic, some selected for their beauty, some for their fragrance, and others for their medicinal virtues. They were systematically arranged in a manner which displayed both artistic taste and horticultural knowledge; and it is safe to say that it would not have been easy to find their equal in that day in any country of Europe or Asia.

FIG. 1.—*Xochinacaztli*, seu *Flos auriculæ*, illustration of Hernandez (1576).

There has come down to us an account of the methods by which this remarkable garden was stocked with some of its most precious plants.

Tlacaelel, the brother of Motecuhzoma Ilhuicamina, the chronicle states, conceived the idea of collecting the waters of Huaxtepec, in the mountains south of the valley, into a great reservoir from which they could be distributed and governed. This work was undertaken and, at his suggestion, a garden was laid out. Messengers were then sent to various parts of tropical America for plants to stock it. From Pinotl, viceroy of Cuetlaxtlan, the Emperor requested, among other rare and beautiful plants, the *yoloxochitl*, or "heart-flower" (*Talauma mexicana*), a single blossom of which was sufficient to fill a whole house with fragrance; the *cacaloxochitl*, or "crow-flower" (*Plumeria rubra*), used by maidens for decorating their hair; the *izquixochitl* (*Bourreria huanita*), with clusters of fragrant salver-shaped flowers; and the *xochinacaztli*, or "ear-flower," the botanical identity of which has long remained a mystery.

The first account of this flower was written about 1569 by Padre Bernardino de Sahagun, who refers to it as *teunacaztli*, "the sacred

XOCHINACAZTLI (CYMBOPETALUM PENDULIFLORUM.) NATURAL SIZE.

ear," and states that it was much used for the sake of its fragrant odor and for drinking, ground up with chocolate.

Francisco Hernandez, the "protomedico," sent by Philip II, in 1570, to Mexico to study its resources, has given a fair illustration of the flower (fig. 1), and describes it under the heading "De Xochinacaztli, seu Flore auriculæ." This description, in Latin, together with the figure, was published in the Roman edition of his work in 1651. The same description, but without the illustration, appeared before this in the Spanish edition of Hernandez, published by Ximenez in the City of Mexico in 1615. It is as follows:

> The *xochinacaztli* is a rare tree, with leaves long and narrow and of a deep green color. Its flowers, borne on a pendent velvety peduncle, are divided into leaves, which are purplish within and herbaceous without, shaped almost exactly like ears, and of a very agreeable odor. It grows in warm countries, and there is nothing else in the *tiangues* and markets of the Indians more frequently found nor more highly prized than this flower. The which is wont to give the greatest charm and taste, together with a very fragrant odor and flavor to that celebrated drink cacao, which they call *chocolate*, and it imparts to it certain tonic properties and wholesomeness as well. It is said that when drunk in water this flower dispels flatulency, causes phlegm to become thin, warms and comforts the stomach which has been chilled or weakened, as well as the heart; and that it is efficacious in asthma, ground to a powder with the addition of two pods of the large red peppers called *texochilli*, with their seeds removed and toasted on a comal which is a kind of griddle on which the natives toast and make their bread, called by us *tortillas*, adding to the same three drops of balsam and taking it in some suitable liquor.

Since the time of Hernandez many works have appeared in which the economic plants of the Aztecs are discussed,[1] but in none of them is the botanical identity of the *xochinacaztli* hinted at, though it is invariably mentioned. That it was to be found in the forests of the Tierra-caliente the author of the present paper felt confident, and he read with interest the accounts of all travelers in southern Mexico and Guatemala who spoke of the delicious flavor of chocolate prepared with the flowers of the *Orejuela*. His discovery of the identity of the flower was almost an accident. While working upon the plants belonging to the Anonaceæ, or Custard-apple family, of Mexico, he came across a photograph in the files of the Bureau of Plant Industry of the Department of Agriculture, showing a number of flowers with their inner petals very much like the human ear in shape. This photograph had been taken by Mr. C. B. Doyle in 1904 while accompanying Mr. O. F. Cook on a mission of agricultural exploration in Guatemala. The flowers were found in the market of the town of Coban, in the department of Alta Verapaz. The photograph is here presented (pl. 1). It was not accom-

[1] The last of these is the work of the Rev. A. Gerste, S. J., published in the Vatican, at Rome, in 1910, entitled "Notes sur la médecine et la botanique des anciens Mexicains."

panied by notes as to the uses to which the flowers were applied, but Mr. Cook, in his journal, states that the flowers of an Anona were offered for sale both fresh and in the form of dried black petals curled up on the edges and heavily veined inside. They had a pleasant, spicy odor. He describes the fresh flowers as having the sepals and outer petals light green and the inner thicker petals of a pale dull salmon color and breaking with a bright orange-colored fracture. No specimens of the plant were collected at this time, but on May 30, 1906, two years afterward, Mr. Cook secured specimens of an Anonaceous plant at Jacaltenango, Guatemala, which he did not associate with the flowers he had seen in the Coban market. On examining these specimens in the United States National Herbarium (sheet No. 574411) the identity of the plant was revealed. The *xochinacaztli* of the Aztecs was no other than the plant described by Dunal from the drawings of Mociño and Sessé as *Cymbopetalum penduliflorum.*

The discovery was announced in a paper read before the Botanical Society of Washington, February 7, 1911.[1] The accompanying illustration, drawn by Mr. Theodore Bolton from the specimens collected by Mr. Cook and from the photograph of Mr. Doyle, will serve for comparison with that of Hernandez, which is also reproduced. The inaccuracy of Hernandez's figure consists chiefly in the fact that the upper flowers shown by him have none of the petals revolute, or incurved along the margin, while the lower flower has all six petals incurved, suggesting the fruit of the aromatic star-anise of Japan. It was a simple matter to test the qualities of the petals by eating one of them. The taste was pungently aromatic and suggested that of a nutmeg, or perhaps a cubeb.

The Xochinacaztli (*Cymbopetalum penduliflorum*) is endemic in the forests of northwestern Guatemala and across the border in the Mexican State of Chiapas. The use of its flowers as a spice gradually died out throughout the greater part of Mexico with the introduction of cinnamon from the East Indies, which is now, together with vanilla, almost universally used for flavoring chocolate. The small tree grows in regions where there is a marked dry and a rainy season, usually associated with coffee, and it could in all probability be cultivated wherever coffee will thrive. Both on account of the fragrance of its flowers and for their application in cooking as a delightful condiment it is suggested that this plant be cultivated.

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[1] See Safford, W. E. "The Rediscovery of the Xochinacaztli of the Aztecs, with notes on Mexican Anonaceae." Science, N. S., vol. 33, p. 470. March 24, 1911.

FIG. 2.—*Cymbopetalum penduliflorum.* Natural size.

FOREST PRESERVATION.

[With 7 plates.]

By Henry S. Graves,
Forester and Chief of Forest Service, Department of Agriculture.

Ten years ago, in the Smithsonian Report for 1901, Gifford Pinchot, then Chief of the Division of Forestry, discussed the subject of forest destruction. He pointed out that the attitude of the public in the United States on the forest question showed two sharply conflicting opinions. One of these regarded forest destruction as an end to be sought in the interest of development. The other regarded forest preservation as an unmixed good and an end in itself always and everywhere desirable. Contrasted with both these views there was set forth another, in words pregnant with the spirit of the unborn conservation movement:

> From the point of view of national progress the one opinion is as mistaken as the other. Both are likely to be survived by that phase of thought which regards forest protection as a means, not an end; which contends that every part of the land surface should be given that use under which it will contribute most to the general prosperity, and the purpose of whose action is best phrased, in the language of President Roosevelt, as "the perpetuation of forests by use."

The progress in practical forest preservation which has been made in the 10-year interval since Mr. Pinchot's article on forest destruction was written may fairly be called startling. In 1901, of the relatively few persons who were alive to the fact that some kind of action must be taken to offset the effects of forest destruction, nearly all either lacked any definite program for the solution of the forest problem or favored remedies which were incapable of meeting the situation. The two remedies commonly proposed were the provision of new supplies through tree planting, largely by farmers, and the reservation of existing supplies through the prohibition of use. As early as 1873 Congress had attempted to promote tree planting as a means of providing timber supplies in the naturally treeless regions, by passing the timber-culture act, which granted homesteads to settlers on condition that one-fourth of the entries should be planted with trees; and the idea that forestation could be developed on a

scale sufficiently large to compensate for the stripping of great areas of timbered country persisted long after the practical failure of the timber-culture act had led to its repeal in 1891. The reservation idea was illustrated in the State of New York by the constitutional prohibition of any cutting on the State holding in the Adirondack and Catskill preserves, and also in the popular understanding (or rather misunderstanding) of what was intended when the western forest reserves of the National Government were first set aside.

The total area of these reserves in 1901 was less than 50,000,000 acres. Their custody was in the hands of the General Land Office of the Department of the Interior. The administrative work of caring for them was confined almost entirely to protecting them against fire and trespass. At the request of the Secretary of the Interior, the Division of Forestry of the Department of Agriculture had begun to make technical studies with a view to showing how forestry might be applied to the reserves; but the resources of the Division of Forestry were hopelessly small, in comparison with the magnitude of this task, and the foresters were without any authority to insure the practice of forest conservation through use, even where they might have known how the thing should be done. The regular scientific staff of the division totaled only 20 persons, and its entire appropriation was but $88,520.

Although the principal effort of the Division of Forestry previous to 1901 had been directed toward the private owner, less than 180,000 acres of private forests were reported in that year as actually under forest management in the United States. Indeed, the vast field of American forestry had at that time hardly begun to be explored. It was almost as much of a terra incognita as was the American continent to the geographers three centuries ago. For except to a limited degree in the eastern part of the country, no basis existed for forecasting what the forests of different regions would produce annually, and therefore of prescribing what should be cut annually; of judging what would be the effect upon the forest of any specific operation; or of insuring forest preservation through use. Whenever the advice of the forester was sought it was necessary to begin by investigating the underlying problems instead of applying knowledge already gathered. In a word, the science on which intelligent use of forest resources depends was only beginning to be developed.

A legal basis for the application of the conservation principle to the forest reserves, or national forests, as they became shortly after the transfer of their administration to the Department of Agriculture on February 1, 1905, had been created by the act of June 4, 1897. This act declared as the purpose of these reserves "to improve and protect the forest or for the purpose of securing favorable conditions of water flows, and to furnish a continuous supply of timber

RANGER'S CABIN ON THE JEMEZ NATIONAL FOREST.

for the use and necessities of citizens of the United States"; and it also authorized the Secretary of the Interior "to make such rules and regulations and establish such service as will insure the objects of such reservations, namely, to regulate their occupancy and use and to preserve the forests thereon from destruction." The same act specifically authorized the sale of timber under methods prescribed by the act and authorized the Secretary of the Interior to permit free use of timber under regulations to be prescribed by him. In other words, the law had explicitly recognized that the forests were not merely hoarded reserves of timber, but public property to be developed, to be occupied, and to be used as well as to be preserved; and further, it recognized that the sum total of these ends could be attained only through regulated use. Yet the only product which the Secretary of the Interior was authorized to dispose of was the timber.

By the act approved February 1, 1905, entitled "An act providing for the transfer of forest reserves from the Department of the Interior to the Department of Agriculture," full authority was given for regulation combined with the securing to the public of a proper return for the use of its resources by private interests for public gain; for this act specified the manner in which "all money received from the sale of any products or the use of any land or resources of said forest reserves" should be disposed of. Thus when the Forest Service took charge of the national forests the way was clear for solving the administrative problem involved in giving practical effect to the policy formulated in the act of June 4, 1897. The national forests now contain a gross area of over 190,000,000 acres. Except in the six States of Washington, Oregon, Montana, Idaho, Wyoming, and Colorado, in which the authority of the President to add further to the area of the national forests was withdrawn by Congress in 1907, practically all the public lands of the United States capable of contributing most largely to the public welfare by their management as productive timberlands or by the effect of their forest growth in protecting water supplies or preventing soil erosion, or by both together, have been put into the national forests. Wherever the timber on these forests is in demand, it is now being sold (or given away where settlement and development can best be promoted by free use) under methods which will not only maintain but also improve the timber growth, and which at the same time safeguard the water supplies of the West. The total amount of timber cut from the national forests last year was nearly 500,000,000 feet; of this the cut under free use was over 100,000,000 feet.

The National Government has also adopted a plan which looks to forest preservation, for purposes of stream protection, in those parts of the country in which there are no longer public lands available for

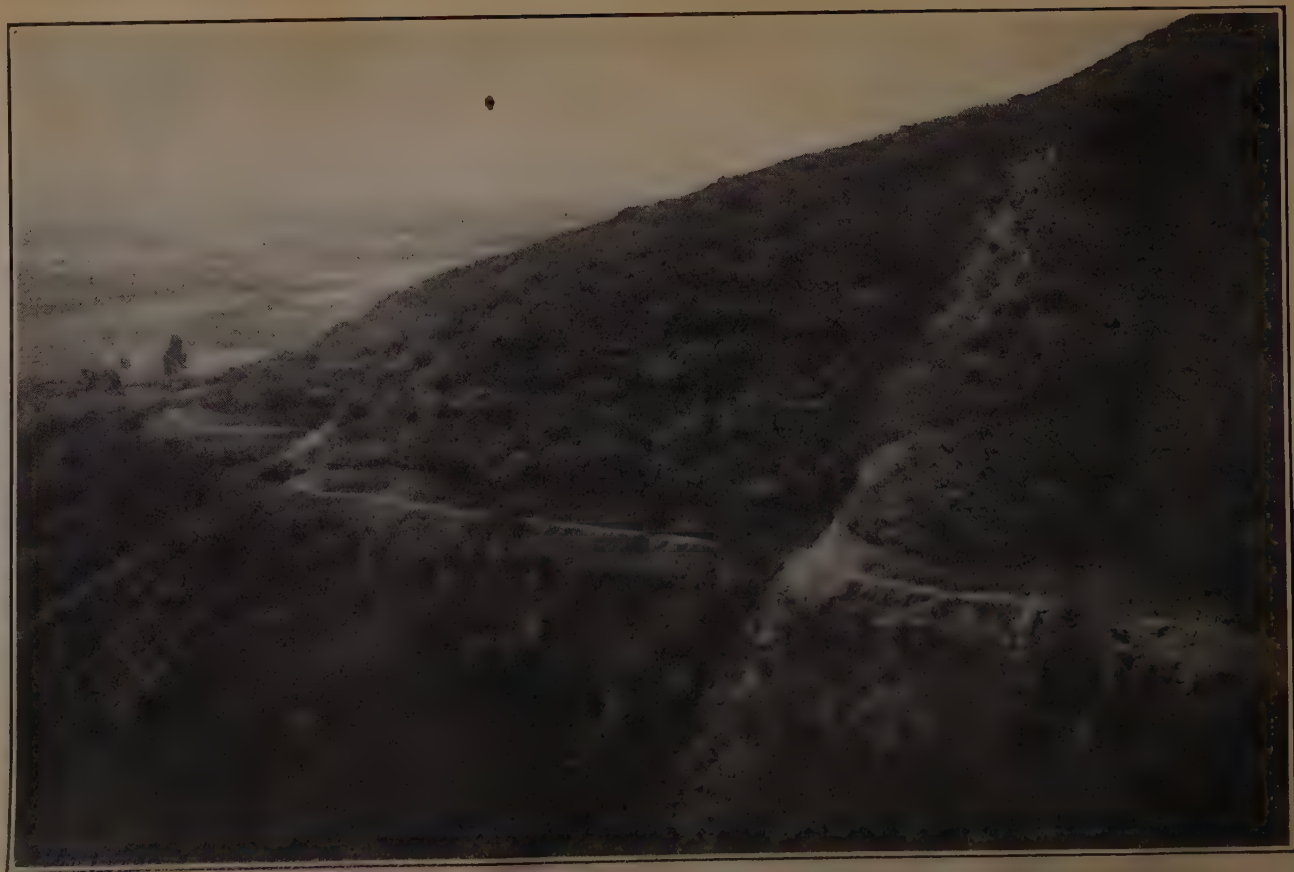
the formation of national forests. Under this plan the Government will both buy land to form eastern forests and will cooperate with States to protect State and private holdings from fire.

Important progress toward forest preservation has also been made as a result of action by the States. Ten years ago the only States which had given much attention to their forest problems were New York and Pennsylvania. In New York the Adirondack and Catskill Preserves had been created and contained a total of about 1,400,000 acres of forest land which the State had undertaken to hold and protect from fire; and a policy of enlarging these holdings by further purchases had been inaugurated. Fire protection of private holdings under a firewarden system had also been begun in New York, the State sharing equally with the towns in the cost of putting out fires. In Pennsylvania a vigorous public sentiment, developed under the leadership of the Pennsylvania Forest Association, had resulted in the creation of a State department of forestry with a commissioner of forestry at its head; in the acquisition of land for State reservations with a total acreage which before the close of 1901 was nearing half a million acres; in provision both for the management and for the sale of timber from these State holdings; and in a fire law which made township constables firewardens. New York and Pennsylvania had both provided for the punishment of persons causing fires. Maine also had a forest-fire law, while Michigan, Minnesota, New Hampshire, and Ohio had State forest commissioners, boards, or bureaus. In Massachusetts the State board of agriculture acted also as a board of forestry, while the New York work was under a forest, fish, and game commission.

At the present time the New York reserves contain, in round numbers, 1,642,000 acres, and those of Pennsylvania 921,000 acres, while Michigan has 232,000 acres, Wisconsin 385,000 acres, Minnesota 51,000 acres, New Jersey 14,000 acres, Maryland 2,000 acres, Indiana 2,000 acres, Vermont 1,700 acres, and Connecticut 1,500 acres. Several other States also have made a beginning toward the formation of reserves.

A most notable advance has been made in State provision of fire protection for private holdings. Generally the first attempts to combat the fire evil took the form of laws providing for the detection and punishment of persons who willfully or carelessly caused forest fires; and the second step was to provide for local wardens, either by adding the duty of firewarden to that of some existing official or by authorizing the appointment of men for this duty exclusively, to be paid for time actually spent in fighting fires. These wardens were usually empowered to employ other help, and often to require the services of men needed to put fires out.

Road Built Along Flathead River. An Example of National Forest Improvement Work.



Real progress began when it was seen that it is much more important, and less expensive to the community in the long run, to aim at fire prevention than to begin to act only after the fire has become formidable, and that to prevent fires main reliance should be placed not on punitive measures, but on an organized, disciplined, and efficient protective force, under a technically trained forester, and regularly employed in watching for fires and cutting down the causes of fire. In heavily forested regions this means patrol during the fire season. It also means such protective measures as the prohibition of brush and fallow burning during the fire season, except under permit, the education of the public as to the harmfulness and the prevention of fires, and watchfulness against such special sources of danger as railroads, campers and fishermen, logging and sawmill outfits, etc. Such a fire-protection system can not, of course, be established without an adequate appropriation. The States of Connecticut, Idaho, Maine, Maryland, Michigan, Minnesota, New Hampshire, New Jersey, New York, Oregon, Pennsylvania, and Washington now have more or less effective systems of organized fire protection, either partly or wholly at the expense of the States.

In certain western States a system of fire protection under authority of the State has developed along a somewhat different line. Timberland owners in the group of heavily forested States in the Northwest, from Montana to the Pacific coast, have on the whole been in advance of the local public sentiment in recognition of the need of systematic fire protection. It is perhaps not to be wondered at that in this region State legislatures were at first not able to see any reason for spending public money to protect private timber which was mainly in large holdings, or that timberland owners should have organized to do at their own expense what the States were not willing to do. The laws of Washington, Idaho, Oregon, and California make it possible for owners, or associations of owners, of timberlands to nominate persons in their own employ for appointment as State firewardens.[1] These wardens receive no pay from the State, but have the authority of the State behind them in enforcing the laws against starting fires. Fire protective associations of timberland owners now exist in Montana, Idaho, Washington, and Oregon; of these the Washington association was the pioneer. Where their holdings border on or are inclosed by national forests they are literally joining forces with the Forest Service, whose protective methods they have closely followed; they generally wish, however, to spend more per acre on protection than the funds at the disposal of the Forest Service permit it to spend in protecting national forest timber.

[1] North Carolina in the East has a similar law.

Only brief mention can here be made of the important advance which has been made by the States in promoting forest preservation through the giving of advice to private owners. This has been done through the appointment of State foresters capable of advising, and expected to advise, those wishing to learn how to apply forestry to their holdings. State foresters, who are technically trained men, have been appointed and are now in office in California, Connecticut, Kansas, Maryland, Michigan, Minnesota, New Hampshire, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Vermont, and Wisconsin. As advisers these men are most useful to farmers and other wood-lot owners who could not afford to call in a professional forester at their own expense, but whose small individual holdings form in the aggregate no inconsiderable part of the timbered area of the East. Notwithstanding the conservatism which is supposed to make the average farmer slow to adopt new methods, it is at least open to debate whether forestry is not making actual progress faster among these small owners than among our lumbermen. Farmers have, indeed, long been practicing a kind of forestry, in that they have been drawing supplies of wood continuously from the same area; and since wood lots are characteristic of parts of the country which have been longest settled and are most densely populated, they are exceptionally favorably situated with regard to markets and the prices obtainable. It is not improbable that, if things are left to take their natural course, improved methods of handling woodlands on the part of small owners may become general in States which have competent State foresters before the owners of large tracts in the great sources of virgin supply are converted to the practice of forest management.

As indifference to forest destruction has been replaced in the public mind by a conviction that the question of future timber supplies is one of serious public concern, a sentiment has developed in favor of legislation to prevent destructive lumbering. The laws which have been proposed look generally toward either (1) the retention of a part of the existing stand, or (2) the lessening of the fire risk after lumbering. Proposed laws of the first kind have set a diameter limit below which timber should not be cut. From the standpoint of technical forestry such a requirement does not meet the need because of its rigidity. Decision as to what trees should be cut and what left in order to make best use of the productive power of the forest can be wisely made only when specific conditions are taken account of. In the same way laws prescribing that all slash must be burned are open to criticism as substituting a rule of thumb for judgment. Fortunately the working out of a better way has followed the proposal of such a law in Minnesota. After a Lake State forest fire conference which brought together last winter representatives of

Minnesota, Wisconsin, and Michigan, and of lumbermen, railroads, and others interested, this Minnesota law was passed in a form which left decision as to the need of brush disposal and the methods to be followed entirely in the hands of the State forester.

The Lake State conference adopted resolutions advocating that the forest-fire protective system of each State should be put under the control of a nonpartisan commission, which should place the work in charge of a technically trained forester; that instead of the present firewarden service of each State there should be organized and maintained an adequate system of patrol; that trails, telephone lines, and lookout stations should be constructed, and that proper safeguards against fire in the form of slash disposal, the establishment of fire lines where necessary, and patrol of railroads should be required. The outcome of this conference must be regarded as a long advance in proposals for State control of fires.

Forest taxation has for years been recognized as an important part of the forestry problem. If taxes are levied annually on timberlands at a high valuation a powerful reason is created for cutting the timber off. Even though the valuation is low, the existence of laws under which timber may, in the discretion of the local authorities, be compelled at any time to pay yearly its full share of a general property tax creates an uncertainty which timber owners generally declare to be a serious hindrance to engaging in forestry. As a matter of wise public policy it is certainly worth while not to make the practice of forestry hard. At the same time, if the existing tax laws are modified on the plea that the peculiar interest of the public in forest preservation calls for a lightening of the burden on forest holdings, the public will have a right to demand that those who benefit by the change shall put forestry into practice.

It must be admitted that as yet large owners have on the whole shown little inclination to take up the actual practice of forestry—that is, to adopt lumbering methods which provide for reproduction and amount to a money investment in the growing of a new crop. There is, however, an important drift toward the making of an investment in what might be called halfway forestry. This appears in the numerous examples of cuttings in which young timber is left to grow, though merchantable, and in which unmerchantable young growth now on the ground is looked after, through care in lumbering or through fire protection, in expectation of a later cut. From this to the actual production of a new crop is but a step, though it may be a long step.

Since four-fifths of our standing timber is in private hands, the problem of conservation as related to this resource must be held far from satisfactory so long as a reasonable expectation of the general practice of private forestry is not in prospect. To regard any such ex-

pectation as justified by present conditions would show an over-sanguine optimism. Lumbermen have not yet reached a point at which they are generally ready to regard their holdings of timberlands as permanent investments. The reasons for this are worth considering. It is a common saying that the only lumbermen who have made money in this country have made it by buying and holding timber. It might be thought that these men would turn naturally to the idea of a permanent investment in productive timberlands. Doubtless they would if the prospective profit were great enough. But hitherto new investments in cheap stumpage have been open to them, either in this country or in Canada, which promised much better returns than money put into reproduction.

As has already been noted, the beginnings of a demand for legislation to compel private owners of timberlands to adopt measures intended to secure the perpetuation of the forest on their holdings has already appeared. Unless private owners themselves forestall action by taking up forestry the pressure for legislation is certain to grow rapidly. When public sentiment first began to awaken to the fact that something was called for to counteract the effects of destructive lumbering, it was frequently said that forest owners should be required to plant a tree for every tree cut down. This plan was generally supposed by its advocates to be that employed in European countries where forest preservation was provided for. Such a proposal is, of course, entirely impracticable, and the idea that it is applied anywhere is based on misinformation. It is true that forest replanting by private owners is required under certain conditions in countries like France and Germany; but the object of the requirement is primarily the maintenance of protective forests, and the method is not that of planting a tree or two trees for every one cut, but calls for a sufficient replanting of the area cut over to establish a new stand. This can be accomplished only by planting a very much greater number of small trees than constituted the mature stand, for a complete forest cover must be secured promptly and the number of young trees required for this is many times greater than the number of old trees. A good mature forest represents the outcome of a long period of competition, during which most of those which began the race have disappeared.

The prescription of a diameter limit may be called the second stage in the evolution of a plan for enforced forest protection accompanied by use. The practical objections to this method have already been indicated. The immediate objects contemplated by this plan are (1) the holding of timber, which, though merchantable, is not yet mature, for additional growth and a later cut, and (2) the starting of a new crop by natural reproduction. In other words, the trees left are expected to act as seed trees. The seed-tree method

Scene in Wasatch National Forest Nursery. Two-Year-Old Douglas Fir in Transplant Beds.

WHITE PINE IN SEED BEDS

of securing reproduction is one of the recognized methods employed by foresters. Like slash burning and the use of a diameter limit, it is not a method which can give good results if applied under any blind and rigid rule. Much judgment must be used in modifying the rule to fit specific conditions if the results intended are to follow.

In California a law was proposed last winter which would have required the leaving of at least one seed tree on every acre of forest land cut over. So far as the writer knows, this is the only case hitherto in which a law has been introduced in any State requiring that seed trees shall be left, except as such trees are provided under a diameter limit.

There are several factors, most of them of a temporary nature, which at present work against the adoption of better lumbering methods. For several years there has been a growing uneasiness among lumbermen because of the evidently increasing criticisms and public disapproval to which their industry has been exposed. Lumbermen feel that they have been subjected to criticism which is unjust. They consider they are in danger of being ground between the upper and nether millstones. They confront a business condition. At present stumpage prices, cost of manufacture, and market prices for their product, their profits are not large. The public chafes at the present cost of the lumber which it consumes. To the average lumberman the difficulties in the way of the practice of forestry, in the light of present conditions in the lumber industry, loom so large that he regards it as impracticable.

For these conditions, however, the industry itself is largely responsible. The question of profit or loss to the lumberman frequently turns on the price at which stumpage is figured on the balance sheet. Stumpage prices have, as is well known, advanced rapidly during recent years. As the available surplus virgin timber dwindled, farsighted lumbermen rushed to get as much as possible into their hands in anticipation of the time when they could sell with a large profit. But prices which mills can get for their product have not moved in proportion to stumpage prices. The reason for this is twofold: The number of sawmills operating in the United States has increased greatly, and the sawing capacity of many old mills has been enlarged, so that to-day the capacity for lumber production is far greater than formerly. Mill owners can not afford to let their property stand idle, and, in consequence, lumber is put upon the market in excess of the actual demand. The second factor which tends to keep down the price of lumber is the inroads made by many substitutes for wood put upon the market in recent years. These inroads in some branches of the lumber industry are serious and have tended to restrict the demand. To the extent that lumbermen have created fixed charges against themselves by buying and holding large amounts of timber,

they are themselves responsible for any embarrassment which may result from their inability to obtain, at the present time, prices for lumber which will enable them to reap the anticipated speculative profit. It is not likely that the public will be willing to bear, in the form of much higher prices for lumber, the burden which the lumbermen have imposed upon themselves. The demand that they be permitted to combine, in order to advance prices as a means of meeting the additional cost which practicing forestry imposes, is one to which it will be exceedingly difficult to secure public assent. Moreover, the additional cost made necessary by the practice of forestry would not be as great as most lumbermen claim. Even under present unfavorable conditions it would in many cases be possible to practice forestry with only such increased cost as the ultimate advantage to the lumberman would fully justify.

Beyond a doubt the sentiment against forest destruction and the demand for the application of lumbering methods which will better utilize and perpetuate the forests will grow stronger. The demand for better lumbering methods will result in the proposal of legislation by the States aimed at regulation of the lumber industry. Some States will try one experiment, some States another. Some laws will doubtless be urged which are unwise. The lumber industry will be on the defensive. It will be compelled to fight drastic and unworkable propositions. When regulating laws are passed, even though they be good laws, the lumber industry will suffer from the lack of uniform laws in different States. The greater the dissatisfaction with the methods of the lumber industry the greater will be the probability of the passage of laws giving scant consideration to what it may have to urge in its own defense.

If, on the other hand, they are ready and able to meet the demands of the public for forest conservation with a constructive attempt to recognize the obligations and the necessities of the situation, so far as they are concerned, advance toward real forestry among private owners may soon become rapid. Progressive lumbermen themselves recognize that the ownership of our timber lands carries with it a certain obligation. To the extent that the lumber industry controls a fundamental resource it is affected with a public interest, and this implies the right of the public to regulate the industry along lines which are not fantastic, but face the actual conditions and are not unjust to the lumbermen.

The alternative to onerous regulation would be the voluntary choice of a course which would satisfy the public that the private owners of forest resources were seeking in genuine good faith to perpetuate them. With such a choice made, the public would not be inclined to demand impossibilities. All that would be necessary would be that the lumbermen should show a reasonable readiness to go as far as is

RED SPRUCE FOREST IN THE ADIRONDACK STATE PRESERVE.

possible for them under existing conditions. What is needed first of all is a spirit of initiative applied partly in doing such things as using reasonable precautions against fire and adopting a forward-looking policy, partly in a thorough study of existing conditions in order to find out what else technical forestry would propose and what the cost would be. There is no reason why the lumbermen should not work out the situation themselves, if they are ready to meet it in a large-minded and constructive way.

In the case of our public forests, as in that of our privately owned forests, preservation through use is fundamentally a matter of investing capital in a growing timber crop. Whenever timber is sold from a national forest such an investment is made. Regulations embodied in the contract of sale require the purchaser to observe certain conditions designed to protect young growth and favor reproduction, while it is stipulated that he shall cut only such part of the stand as the forest officers may mark for removal, and the purpose of the marking is to secure the future welfare and a high productiveness of the forest. The Government therefore invests in making such sales:

(1) The equivalent of the increase in the cost to the purchaser of cutting timber under requirements of brush piling, avoidance of injury to young growth, and smaller amount of stumpage obtainable per acre because of the timber reserved. This increase in cost of lumbering falls on the Government through lower prices, which a purchaser required to observe such conditions is willing to offer for the stumpage.

(2) The actual stumpage value of all merchantable timber reserved from cutting whenever the purchaser would have been willing to increase his purchase by this amount had he been given opportunity to do so.

(3) The direct cost to the Government of planning the sale with a view to benefiting the forest, of marking the timber, and of supervising the sale to insure observance of the conditions framed to preserve the forest.

In other words, just as the private lumberman, if he were able to apply forestry and pay the added cost of operating out of his receipts, would be reinvesting a part of his profits; so the cost of handling timber sales on the national forests is largely chargeable to capital account on any sound scheme of forest finance. The average price realized for national forest stumpage last year was $2.44 per 1,000 board feet. The average cost of these sales to the Government may be put at from 30 to 50 cents per 1,000, a figure which would be much lower were not so many of the sales on National Forests for small amounts. This latter amount may be regarded as the sum of two very different expenditures. One is the expenditure

incident to the sale itself as a business transaction. When a purchaser cuts timber under an agreement to pay the owner a certain amount per 1,000 feet the owner must measure the amount cut. The cost of doing this should be counted as a current expenditure. On the other hand, that part of the cost of timber sales which goes back into the forest, so to speak, should be reckoned differently. It is a betterment expenditure.

Of course, such a point of view as this is not easily reconcilable with the methods customary in handling Government expenditures. The national finances do not ordinarily make a distinction between money expended as capital investment and money disbursed for current expenditures. Both are paid alike from current receipts. I merely wish to point out that in order to judge properly as to the true character of the work of managing the national forests it is necessary to look at them from the standpoint of the business man and to distinguish between actual running expenses and investments on capital account.

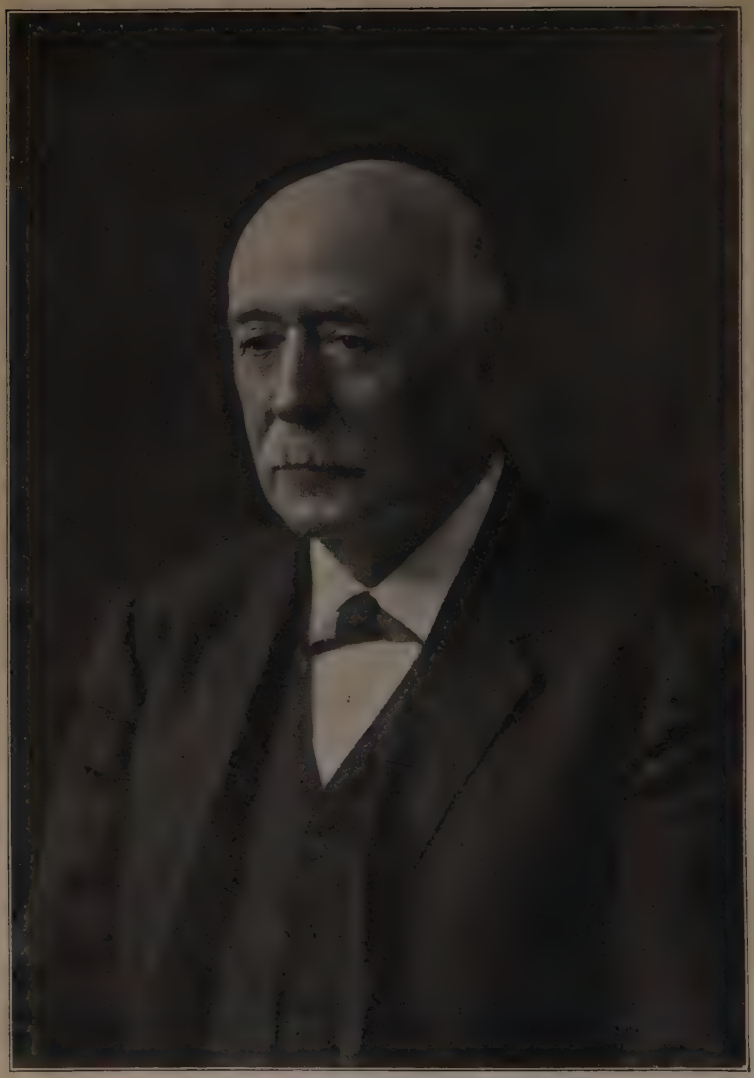
A more obvious investment on capital account, which forms a considerable part of the annual expenditures of the Forest Service, is found in the expenditures for so-called "permanent improvements." Both the protection and the use of the forests depend on their equipment with roads, trails, telephone lines, fire lines, watch towers, rangers' cabins, fences and water tanks in connection with handling stock, and various other works of construction. Plainly, expenditures made for these purposes should not be combined with expenditures necessary for the transaction of current business and a balance struck against receipts if the result is to be used as the basis for a judgment as to whether or not the forests are paying.

Another very large item in the total cost which national forest administration entails is the cost of protecting the forests from fire through the maintenance of a protective force. The national forests contain over 500 billion board feet of timber. Only a very small part of this is now within reach of a demand which will enable the Government to sell the timber, except at a great sacrifice in price, if at all. A private owner who was protecting timber which was not ready to cut would treat the cost, from an accounting standpoint, precisely as he would the cost of paying taxes on the timber. In other words, it would amount to an annual increase in his investment. The question whether the expenditure was wise would not in the least depend on whether he was getting back anything from the forest or not. If his final profit is enough greater than what he could realize now to more than cover the cost of holding the timber, he has done well to hold it.

While it would be well worth while, from the standpoint of money receipts, for the Government to protect the great amounts of timber

which are now unsalable in anticipation of the time when they will be salable, it must never be thought that the question of money profits is the vital one. The interest of the public in the preservation of the existing supply of national forest timber is much more than an interest in what it will sell for. It is an interest in preserving the supply of material necessary to the carrying on of many industries.

More than this, it is an interest also in the continuation of the benefits obtained from the forests in other ways than from the use of timber. Many of the national forests were created, and are protected, not because they furnish valuable supplies of timber, for they do not; but because they protect much more valuable supplies of water. If the question of the wisdom or unwisdom of the national forest policy were to be tested by balancing expenditures against receipts it would follow that the first thing to be done would be to get rid of forests from which a net income is not either now being obtained or reasonably to be expected. This would throw out almost the whole national forest area in southern California; large parts of the forests in Arizona and New Mexico, maintained for the protection of projects developed or to be developed by the Reclamation Service; and much of the present area of the national forests in other States. Neither public sentiment nor the public interest could permit this. The national forests are a gigantic public undertaking, conceived with a view to the future. They are like a system of public works in process of construction. It would be almost as absurd to settle the question whether the Panama Canal is worth while on the basis of income, compared with the expenditures at the present time, as it would be to answer the same question in the case of the national forests by the same method. The application of any such test is equivalent to the adoption of the policy of "scuttle." It is not to be imagined that public sentiment would permit the adoption of any such policy, were it proposed.



ALEXANDER AGASSIZ, 1835-1910.

ALEXANDER AGASSIZ, 1835–1910.[1]

[With 1 plate.]

By Alfred Goldsborough Mayer,
Marine laboratory of the Carnegie Institution, Tortugas, Fla.

Alexander Emmanuel Rodolphe Agassiz, only son of Louis Agassiz, was born at Neuchatel, Switzerland, on December 17, 1835.

The great English statistician Galton found that men who attain eminence in science are nearly always sons of remarkable women, and Alexander Agassiz was no exception to this rule. His mother was Cecile Braun, the daughter of the postmaster general of the Grand Duchy of Baden, who was a geologist of note and the possessor of the largest collection of minerals in Germany. Cecile Braun was a woman of culture and an artist of exceptional ability, and she was the first who labored to illustrate the early works of Louis Agassiz, some of the best plates in the "Poissons fossiles" being by her hand. Her brother, Alexander Braun, after whom her son was named, was a distinguished botanist and philosopher, and another brother, Max Braun, was an eminent mining engineer and geologist and the director of the largest zinc mine in Europe. Thus we find that intellectual superiority was characteristic of both the paternal and maternal ancestors of Alexander Agassiz.

After the birth of her son sorrow came upon the family, for the heavy expenses demanded by the publication of Louis Agassiz's numerous elaborate monographs, with their hundreds of illustrations, had exhausted not only their author's means, but had drained the resources of the entire community of Neuchatel in so far as they could be enlisted for the cause of science. Thus in March, 1846, Louis Agassiz was forced to leave Neuchatel and to begin the long journey toward America, where he found a wider field for his great endeavors. Before his wife or children could follow him to his new home she died in 1848, after a lingering illness.

I cite these events because they show that the early youth of Alexander Agassiz was passed in a period of domestic confusion and sorrow, which may have left its mark upon him throughout life, for his

[1] Reprinted by permission from the Popular Science Monthly, vol. 76, No. 5, Nov., 1910.

great self-reliance was a characteristic rarely developed in those whose early years have been free from care. Life was a severe struggle for him, and though his victories were great they were won after hard-fought battles.

After the departure of his father from Neuchatel Alexander remained with his mother throughout the period of her failing health, and after her death his father's cousin, Dr. Mayor, and the Rev. Marc Fivaz brought him to America, where he rejoined his father in America in June, 1849, and entered the Cambridge high school in the autumn of the same year.

The earliest published picture of Alexander Agassiz is by his father's artist, Dinkel, and appears upon the cover of the first livraison of the "Histoire naturelles des Poissons d'Eau douce de l'Europe Centrale," published in 1839. It shows him as a little boy of 4 years fishing upon the shore of the Lake of Neuchatel.

In early life Alexander exhibited his independence of character and incurred the Prussian governor's displeasure and his father's reproof through his willful neglect to salute this official when he passed upon the opposite side of the street. He must also have shown his characteristic pertinacity, for before he came to America he could play well upon the violin, an accomplishment which he allowed to fall into abeyance in later years.

In the spring of 1850, soon after the arrival of Alexander in America, his father took for his second wife Miss Elizabeth C. Cary, of Boston, in whom he found a new mother throughout life, and he took the most tender care of her until her death, long years afterwards, when he himself was an old man. Doubtless many of the finer traits of his rugged character were developed through the refining influence due to the care and teaching he received from this superior woman.

Nature and his father made him a naturalist, and his reverence for his father was almost a religion with him. He became the first student his father taught in America.

He entered Harvard College and graduated in 1855 with the degree of A. B., and then studied engineering, geology, and chemistry in the Lawrence scientific school, obtained one B. S. in 1857 and another in natural history in 1862. During his college days he was much interested in rowing and was bow oar of the four-oared crew which won the race against Yale on the Connecticut River at Springfield on July 22, 1855, at which time he weighed only 145 pounds. He continued to row on the university crew until 1858, when the future President Eliot was one of his comrades in the boat.

After graduating from the Lawrence scientific school he studied chemistry for a few months at Harvard, and then taught in his father's school for young ladies until 1859, when he was appointed

an assistant on the United States survey, and departed to take part in the task of charting the region of the mouth of the Columbia River, Oreg., and in establishing the northwest boundary. During this visit to the Pacific coast he found time in intervals of travel between official duties to study the fishes and medusæ of San Francisco Harbor and Puget Sound, and to collect specimens at Acapulco and Panama for his father's museum; but after a year's absence he acceded to his father's earnest request and came home to Cambridge to continue his zoological studies and to assist in the upbuilding of the great museum which was the dream of his father's life.

We now come to the period of the beginning of his scientific productivity, for in 1859 he published his first paper—a brief address before the Boston Society of Natural History upon the mechanism of the flight of Lepidoptera. It seems strange that this first paper of one who was destined to devote his life to the study of marine animals and to the sea should have been upon butterflies and moths. Moreover, it is his only paper save one upon a mechanical principle underlying animal activity, his later work in zoology being of a systematic, descriptive, or embryological character.

These years when he worked by his father's side and assisted him from the time the museum was formally opened in 1860 until 1866 when he went to Michigan to develop the Calumet and Hecla copper mine were probably the happiest of his life. At first he had charge of the alcoholic specimens, of the exchanges and the business management of the museum—sufficient to swamp an ordinary man; but he was a hercules of energy and executive power, and his remarkable ability as an organizer probably saved the museum from many an embarrassment which his father's buoyant enthusiasm and simple faith in destiny might have brought upon it. He had much of that ardent love of the study of nature which was his father's own, but it was tempered and controlled by a more conservative judgment and a keener insight into the motives of men, so that the two working in sympathy together made an ideal team for drawing the museum upward from obscurity to prominence; for these early days were critical ones in its history. In 1866, when his father was absent in Brazil, Alexander Agassiz had entire charge of the museum.

On November 15, 1860, he married Miss Anna Russell, daughter of George R. Russell, a leading merchant of Boston. The wedding took place at the home of the bride's brother-in-law, Dr. Theodore Lyman.

Arduous as his official duties were from 1859 to 1866, when he studied in the museum at Cambridge, they did not prevent his accomplishing a remarkable amount of work in science, for he devoted his summers to study upon the seashore at a time when the waters of many a now polluted harbor were pure, so that he discovered many new and remarkable marine animals in the neighborhood of Boston,

where now nearly all aquatic life has disappeared. He produced 18 publications during this period, the most notable being his illustrated catalogue of the "North American Acalephæ," containing descriptions of many new and interesting forms of medusæ from the Pacific and Atlantic coasts, and illustrated by 360 figures drawn from life by his own hand. It is but a just tribute to his thoroughness as a collector and observer to say that some of these medusæ have never again been seen since he discovered them off the New England coast 50 years ago.

Another interesting paper of this period is his "Embryology of the Starfish," of 66 pages, illustrated by 8 plates containing 113 figures beautifully drawn from life by the author; and yet another paper is upon the young stages of annelid worms in which he shows that in past ages adult worms were often provided with very large bristles, and that the young of existing marine worms still have such structures.

At this time also he wrote much upon echinoderms, and made substantial progress upon that great work of his early manhood, the "Revision of the Echini," which finally appeared in four parts between 1872–1874 and consists of 762 quarto pages of text and 94 plates; composed of drawings and photographs made by the author. This work caused his father keen delight, for he foresaw that it portended a distinguished career in science to his gifted son. It won the Walker prize of $1,000 from the Boston Society of Natural History, and brought to its young author an international reputation.

In 1866 he was elected to membership in the National Academy of Sciences, which at that time recruited itself from the active young workers of the country. He was president of the academy from 1901 to 1907, and its foreign secretary from 1891 to 1901 and from 1908 until his death in 1910. He bequeathed $50,000 to the academy. He was also deeply interested in the American Academy of Arts and Sciences and served as its president, gave large sums to it and left it $50,000 after his death. These two academies were the only scientific associations of America in which he took any active interest.

Between 1860 and 1866 he laid the foundation for all that he was to achieve in science, with the exception of his elaborate explorations of coral reefs, and, with this exception, all of the subjects which were to engross his attention in future years were then engaging his active interest. He never departed from the thought and method of these early days, and he always spoke of them with loving remembrance as "the good old days"—their influence upon his scientific career was paramount. For example, he never adopted the methods of the histologist, which were not used by his father, and he confined himself to the study of living animals whenever this was possible. Thus it is that he ranks among the foremost of those systematists and em-

bryologists who have devoted themselves to the observation of marine animals, but histology was wholly neglected by him. Nor did he ever take part in that stirring discussion of Darwinism which engrossed the attention of all of his contemporaries. It would be unfair to say that he did not believe in evolution, but the truth is that he was but little interested in the speculative side of science, excepting in so far as its deductions could be based upon observations of facts. In later life he came to regard the labors of the physiologist and of the laboratory experimenters upon the reactions of animals as beyond the scope of zoology.

But the walls of the museum and problems of zoology were too narrow a bound for such a genius of activity as Alexander Agassiz; moreover, he was poor and he required funds for the prosecution and publication of his work in science, and thus in 1865 he engaged in coal mining in Pennsylvania, and in the following year he temporarily left the museum and became superintendent of the then unprofitable Calumet copper mine on the southern shore of Lake Superior, and in 1867 he united the Calumet with the adjacent Hecla mine, calling the combined property the Calumet and Hecla. It is due more to him than to any other man that this mine has produced the largest profits ever divided by any incorporated mining company, for the dividends up to December 31, 1907, amounted to $105,850,000. From the first days of his leadership in its affairs the company excelled all other mines in the introduction of heavy machinery and modern methods. Indeed, its life depended upon the development of methods of mining upon a large scale, and so vastly has it grown that 83,863,116 pounds of fine copper were produced in 1907. As superintendent and director and afterwards as president of the company, Alexander Agassiz steadily pursued the policy which led to this extraordinary industrial success, and out of the wealth it brought him he devoted upward of $1,000,000 to forwarding the aims of the museum which his father had founded, until he made it famous throughout the world for its excellent publications in science. He also expended large sums upon numerous scientific expeditions, the results of which he published in a manner that has never been excelled.

To have developed the greatest copper mine in the world would have taxed the entire energy of many an able man, but so extraordinary was Alexander Agassiz's capacity for productive labor that he became the sole author of 127 notable scientific works, many of them large books with numerous plates and illustrations drawn by himself, and he published many other minor papers. He was also the joint author of 18 and the patron or inspirer of more than 100 more, which were written by specialists in America, Europe, and Japan, to whom he sent the collections he had gathered.

In his treatment of assistants and collaborators he displayed a most commendably unselfish spirit, and indeed the only differences I experienced during eight years in which I served as his assistant were occasioned in persuading him to permit his name to appear as the senior author of publications which were actually the result of our joint efforts.

Labor at the copper mines made enormous drains upon his seemingly inexhaustible energy, for during the early years of his connection with the company he worked upon an average of 14½ hours each day. Yet, arduous as these duties were, between 1867 and 1874 they made but little difference in the output of his scientific work, for in this period he produced 19 papers, one of them being his famous "Revision of the Echini." Another announces the discovery that *Tornaria* is undoubtedly the larva of *Balanoglossus*, and in another he proves that the peculiar pincer-like organs found upon the echini are in reality only highly modified spines, and they serve to keep the animal clean by actually grasping and removing detritus from the surface of the creature. In another work of this period he presents a paper illustrated by 202 excellent figures and giving a complete account of the embryology of those most diaphanous of marine animals, the Ctenophoræ.

Indeed, it may be said that, while his later work was far more elaborate and widely known, it was not more brilliant than that of this period which closed with his fortieth year, and these older papers are of such fundamental importance that they are quoted in all general text-books of zoology. We see, then, that these days of his early manhood between 1861 and 1873 were rich in achievement in science and remarkable in other respects, for it was during this period that he raised himself from poverty to wealth more than sufficient to meet the demands of his expensive researches in zoology.

But the "happy old days" were soon to pass away forever from the life of Alexander Agassiz, for on December 14, 1873, his great father died, and to deepen his misery his wife, to whom he was devotedly attached, passed away only eight days after his father's death, and his own health, undermined by too strenuous labor, failed so seriously that throughout the remainder of his life he suffered from an impairment of the circulation which obliged him to seek a warm climate every winter.

Those who knew him in his happier years say that from this time onward a great change was observed in him. These irreparable losses came upon him at a time when youth was gone, but middle age had hardly come upon him and most things of life were yet in store for him. Henceforth he was to live alone with his sorrow, master always of himself, simple almost to austerity in his tastes, but deprived of that sympathy which only a wife could give, it is but little to be

wondered at that he raised a wall between himself and the great unsympathetic world, which only those nearest to him and a few most intimate scientific associates could penetrate. In early life he had been buoyant in spirit, popular and beloved by all who knew him, but after the sorrows of 1873 he withdrew from broader contact with the world, and, while he still remained cordially intimate with a few of the greatest leaders, from the rank and file of scientific men he held himself far and aloof. One must always bear the fact in mind that during the last 37 years of his life he was a saddened and an ill man—one whose deepest love was buried and whose fondest hopes had been wrecked. We must also consider that a tendency toward this reserve probably came to him through inheritance from the German blood of his mother's side of the house, and it may in some measure be accounted for by the fact that English always remained a foreign tongue to him, for he thought in French, and in temperament he remained European rather than American.

Yet among scientific men he became the greatest patron of zoology our country has known. In 1910, at the time of his death, the fifty-fourth volume of the "Bulletins" and the fortieth volume of the "Memoirs" of the Museum of Comparative Zoology were appearing. These publications had been started in 1863 and 1864, and in the number of important and beautifully illustrated papers they contain they have been excelled by only a few of the most active scientific societies of the world; yet the expense of producing them has largely been borne by one man—Alexander Agassiz.

In 1870–71 he visited many European museums to study specimens of echini for his great work upon this group and he was also especially interested in the results of the English deep-sea dredging expeditions in the *Porcupine*, little dreaming that he was himself to become a great leader in such work.

In 1873 when Mr. John Anderson, of New York, offered his father the island of Penikese as the site for a marine biological laboratory, Alexander Agassiz used all his efforts to dissuade him from its acceptance, but failing in this he served for the first year as an instructor and the second as superintendent of the school. He gives a history of this experience in an article in 1892 in the Popular Science Monthly, volume 42, page 123. Mr. Anderson's final loss of interest in the laboratory and his refusal to consent to its removal to Woods Hole led to its abandonment. Although Alexander Agassiz, prompted by his deep interest in marine zoology, did not give up the attempt to maintain the school until after an appeal for aid addressed to the superintendents of public institutions and presidents of State boards of education throughout the United States had met with inadequate response. Then he himself paid the expenses and the Penikese School passed out of existence.

His experience at Penikese was, however, by no means in vain, for it deeply impressed him with the advisability of establishing a summer school for research in marine zoology, so that in 1877 he built upon his place at Castle Hill, at the mouth of Newport Harbor, an ideal little research laboratory which afforded excellent accommodations for half a dozen students at a time. For 18 years students and instructors from Harvard College visited this charming spot, and many are the papers which resulted from their labors there. Count Pourtalès, W. K. Brooks, Fewkes, and Whitman were the first workers in the station, and each year about 10 of the most promising of the research students in zoology at Harvard were privileged to study at the Newport laboratory. Every day a stage bore them from the town, 4 miles away, to the laboratory and back again at 5 o'clock in the afternoon, after the daily swim in the ocean. The laboratory was excellently equipped with reagents, glassware, and large tanks provided with running salt or fresh water. The microscope tables were set upon stone foundations to avoid vibration, and a good little steam launch lay at her moorings in a near cove, ready to dredge in the service of science. I treasure the memory of those youthful days at Newport, when the enthusiastic spirit of our great leader was an inspiration to each and every one of us, and I recall his delight over the rare "finds" we occasionally discovered in the surface tow, which was made every night and lay awaiting our study in the morning. Gradually, however, a change came over the Newport laboratory; the once pure water of the harbor became more and more polluted as population and shipping increased, until finally, in 1897, students were no longer invited to come to Newport, and the scientific existence of the laboratory ceased. An account of the laboratory, together with a plan of the building, will be found in Nature, volume 19, pages 317–319, 1879, and in the Century Magazine for September, 1883, but these fail to give an idea of the attractive little vine-clad building nestled down on the slope of the shore, overlooking its little cove with the beautiful bay to the northward and the ocean on the south.

Alexander Agassiz was the first to see that the southern shore of New England was most favorably placed for the site of such a station, for he discovered that here arctic forms are carried down during the winter and early spring, whereas late in summer the southerly winds bring drifting upward from the Gulf Stream animals whose true homes are in the warm waters of the tropical Atlantic, and thus one meets with an extraordinary seasonal variation of marine life on the southern coast of New England.

In 1874 Alexander Agassiz was elected curator of the museum, to succeed his father in this responsible position, and indeed the prospects of the museum were at that time such as to inspire grave appre-

hension, for its annual income was but $10,000, while it had a debt of $40,000, and only four-fifths of the north wing was completed. Fortunately, however, the devotion of the country to the memory of the great Louis Agassiz was such that the museum was not allowed to fail as had the school at Penikese. Over $310,000 were raised by popular subscription and through State grants for the support of the museum and as a memorial to Louis Agassiz, $25,000 being contributed by Alexander Agassiz himself. It is interesting to see that $1,215 of the amount was subscribed by 1,233 workmen of the Calumet and Hecla, although there were at that time not more than 1,400 men at the mine.

From 1874 Alexander Agassiz remained the actual, although not constantly the nominal, head of the Museum of Comparative Zoology, and from 1902 until his death in 1910 he bore the title of director of the Harvard University Museum.

The growth of the museum building was slow but constant. Alexander Agassiz himself completed the construction of the zoological section in 1882 and other public-spirited men and women, including his two sisters, contributed to build other parts of the edifice, until at present only 100 feet of the southern wing of the building planned so long ago by Louis Agassiz remains to be completed. The total cost of the building has been more than $1,200,000, and its invested capital amounts to somewhat more than $900,000. Thus, while it is much hampered for funds, it still remains the greatest university museum in the United States. The zoological section has been greatly enriched by collections gathered by Alexander and Louis Agassiz, and their gifts to the library have placed it in a position in which it is unsurpassed in America, more than 6,000 bound volumes having been presented by Alexander Agassiz himself.

In the classification of its zoological exhibits the museum is one of the clearest existing models of the system of Cuvier, for it must be remembered that intellectually Louis Agassiz was Cuvier's son, and Alexander Agassiz steadfastly pursued his father's plan in so far as the museum's exhibits were concerned.

No family has striven more effectually for the intellectual uplifting of Harvard than that of the Agassiz, and it is to be regretted that the great museum which they founded and fostered does not officially bear their name, but instead is described by an almost meaningless phrase, "The Museum of Comparative Zoology."

Alexander Agassiz was a loyal son of his alma mater and he served as an overseer of Harvard from 1873 to 1878 and again in 1885, and he was a fellow from 1878 to 1884 and from 1886 to 1890. In 1885 the university conferred upon him the honorary degree of LL.D.

The year 1875 marks the beginning of Alexander Agassiz's career as a leader of expeditions, for with Dr. Samuel Garman as his assist-

ant he explored Lake Titicaca and the coast region of Peru and Chile. From this time onward until the close of his life exploration was to engross more and more of his attention, to the final exclusion of the embryological studies that had given color to his earlier years. The last publication in which he records the results of the rearing of animals is his joint paper of 1889 with Prof. Cha les O. Whitman, and is upon the development of fishes. After 1889 h gave up the raising of larvæ in his aquaria at Newport and became an explorer, geologist, and systematic zoologist, although it should be said that the last paper published during his lifetime is a short one upon the temporary existence of a lantern and of teeth in the young *Echinonëus*. It is, however, based upon the study of museum material and records an observation made by A. M. Westergren.

His remarkable energy and executive ability fitted him in an eminent degree to be the leader of scientific expeditions. Each exploring trip was planned to a day even to its minute details, every course charted, distances measured, and every station decided upon before he left his desk in the Harvard Museum, so that all of its achievements were actually prearranged. At times it was of vital import to his expeditions to have supplies of coal brought to some distant island in the Tropics, but invariably when he arrived his colliers would have preceded him, and all went forward with clockwork regularity. In fact, before starting he read all that was to be found upon the regions he designed to visit, so that he was enabled to begin the writings of his results the moment the voyage was over. It is due chiefly to his forethought that in more than 100,000 miles of wandering over tropical seas he never met with a serious accident; and this is the more remarkable when one considers that in order to land upon the coral reefs he was forced to cruise in the hottest season, when the brooding calms were liable at any moment to break into a hurricane. Day after day I saw him remain upon the bridge of the steamer sketching salient features of many a lonely coast that he of all naturalists was the first to see. The rolling of the vessel caused him acute distress, yet, though seasick, he worked on undaunted, for the keynote of his character was pertinacity.

As we have said, his first expedition was to South America to explore Lake Titicaca and to visit the copper mines of Peru and Chile. He published a hydrographic chart of the lake, sounded its depths, determined its temperature, collected its animals and plants and relics of the ancient Peruvians, who once lived upon its islands. Among other results he found at Tilibiche, Peru, a reef of fossil corals elevated 2,900 to 3,000 feet above the sea and 20 miles inland from the ocean, thus showing that the recent elevation of some parts of the western coast of South America has been even greater than had been observed by Darwin.

Upon returning from South America, his embryological studies were resumed at Newport, and the development of flounders and other young fishes interested him especially. It was well known that in the young flounder the eyes are on both sides of the head and that after the fish falls over on one side, the eye of the lower side travels around and comes to lie beside its fellow on the upper side of the fish, but Alexander Agassiz discovered that in the transparent young of flounders allied to the Plagusiæ the lower eye actually penetrates through the tissues of the head and reappears on the surface of the upper side of the fish.

In the young of other bony fishes he discovered a caudal lobe showing that in an early stage the tails of the bony fishes resemble the adult tails of the more ancient ganoids.

He also found that under the skin of flounders there are yellow, red, and black pigment cells and that changes of color are due to the independent expansion or contraction of these several cells; and in 1892 he made the interesting discovery that if young flounders be placed for six weeks in aquaria with white surroundings they lose nearly all color and do not regain their normal color, even if at the end of this time they be surrounded by black.

These studies of fishes, begun in 1875, were continued for many years in the intervals between expeditions, the last of the series being published in 1892. One of the most important papers of this series appeared in 1878 and is upon the development of that archaic fish the gar pike, *Lepidosteus*.

But of all animals the echinoderms interested him most deeply. Indeed of the 145 most important scientific papers of which he was sole or joint author 45 treat of echinoderms. Accordingly in 1874–77 we find him actively engaged in their study. In 1874 he announces the discovery that hybrid larvæ may be produced by artificial means between the two common species of star fish of the New England coast. In 1876 he studied the structure of some viviparous echini from the Kerguelen Islands, and found that they habitually carried their young about with them until the young had acquired most of the characters of the adult. In 1877 his beautifully illustrated work upon North American star fishes was published.

In 1876 he was keenly interested when he visited Sir Wyville Thomson in Scotland and inspected the vast collections of deep-sea forms brought home from the three-years' cruise of the *Challenger;* and it was a happy moment for him when in 1877 an arrangement was perfected with the United States Government by virtue of the terms of which he was given the scientific direction of the United States Coast Survey steamer *Blake* during the entire time of her purposed explorations of the West Indian and Gulf Stream region. He joined the *Blake* at Habana, Cuba, in December, 1877, and remained

on board until April, 1878, exploring the Gulf of Mexico and adjacent regions. Admiral, then Lieut. Commander C. D. Sigsbee, United States Navy, was in command, and his ingenious inventions of sounding apparatus, trawls, etc., enabled the expedition to accomplish unprecedented results.

The second cruise of the *Blake* started from Washington on November 27, 1878, with Capt. J. R. Bartlett, United States Navy, in command, and throughout the winter of 1878–79 they cruised among the Windward Isles of the West Indies and over the Caribbean Sea, visiting Habana, Jamaica, Haiti, Porto Rico, St. Thomas, Santa Cruz, Montserrat, St. Kitts, Guadeloupe, Dominica, Martinique, St. Lucia, St. Vincent, Granadines, Grenada, and Barbados, and gathering an immense collection of animals from the depths of the ocean.

The third and last cruise of the *Blake* was for the purpose of sounding the depths of the Gulf Stream. They started from Newport in June and cruised until August, 1880, running seven lines of soundings off the coast between Charleston and George's Bank, which led to the discovery that a plateau covered by water not more than 600 fathoms deep extends from the Bahamas northward to Cape Hatteras, forming a vast triangular area of shallow water, the outer edge of which is from 300 to 350 miles out in the ocean from the coast of the Southern Atlantic States. The Gulf Stream flows across this area on its course between the Straits of Bemini to Cape Hatteras, and the outer edge of this shallow bank is where the North American Continent rises abruptly from the depths of the flat floor of the ocean. The name "Blake Plateau" was most appropriately given by Alexander Agassiz to this extensive area of shallow water.

During her three cruises the *Blake* made 355 soundings, deep-sea temperature observations, and trawl hauls yielding a phenomenally rich harvest of new and interesting marine animals. Among other things, the second cruise led to the discovery of a vast submarine valley, the "Bartlett Deep," extending for nearly 700 miles along the southern coast of Cuba toward Honduras. Twenty miles south of Grand Cayman this great depression is 3,400 fathoms deep, so that the summits of the mountains of Cuba only 50 miles away are 28,000 feet above its somber trough.

This experience upon the *Blake* was the most momentous event in Alexander Agassiz's scientific life, for it gave him a taste for marine exploration which was to dominate his future career. Without this he might have continued to be an embryologist and systematic zoologist, but he was destined to more conspicuous achievements as an explorer.

Its effect upon the history of the museum at Cambridge was also profound, for the output of museum publications had been so slow that at the end of 1877 only three volumes of the "Bulletins" and

five volumes of the "Memoirs" had been completed, and yet these publications had been appearing in parts for 14 and 13 years, respectively. The reports upon the great collections gathered by Alexander Agassiz's expeditions gave these museum publications an enormous impetus, so that at the time of his death in 1910 the fifty-fourth volume of the "Bulletin" and the fortieth of the "Memoirs" were appearing.

Alexander Agassiz realized that the Government had always failed to provide adequately for the publication of the results of its many explorations, and thus he himself assumed the direction and defrayed the entire expense of all of the publications resulting from expeditions under Government auspices of which he was the scientific director. No results of explorations have been more appropriately published or better illustrated than those under the auspices of Alexander Agassiz.

Alexander Agassiz did most wisely also in sending the various collections not only to specialists in America, but to the leading students in Europe and Japan, thus securing the cooperation of those best competent to pronounce upon them.

During the first cruise of the *Blake* he discovered that the prevailing winds blowing over the Gulf Stream caused a marked concentration of floating life upon its western edge, and that this aggregation was nowhere richer than at the Tortugas, Fla. Accordingly, under Government auspices he visited the Tortugas in March and April, 1881, with Dr. J. W. Fewkes as his assistant. Although greatly hindered by stormy weather, he succeeded in securing a large collection of marine animals, notably the Porpitidæ and Velellidæ, an elaborate and fully illustrated account of which he published in 1883, and in the same year, in the "Memoirs" of the American Academy, he presented the results of his studies of the fine coral reefs of the Tortugas.

His *Blake* Echini appeared in 1883, and in 1888 came his last *Blake* publication, a general account of her three notable cruises. This crowning work comes nearer to being a popular book than anything he, as sole author, ever published. It is a general review of the results of the *Blake's* voyages between 1877 and 1880, and it appears in volumes 14 and 15 of the "Bulletins" of the Museum of Comparative Zoology, being illustrated by 545 maps and figures of the highest artistic and scientific merit.

It is rarely, indeed, that the results of exploration have been thus summarized in a single work, and none gives a clearer idea of the strange forms of the creatures that live upon the cold, dark floor of the deep sea than does this one.

The results may be significantly summarized by stating that we now know more of the topography and of the animals of the depths

of the Gulf Stream and West Indian region than of any submarine area of equal extent in the world, and that this knowledge is due to the explorations of the *Blake* under Alexander Agassiz's scientific direction. It is but just to add that these notable achievements would have been impossible had it not been for the inventive genius and intelligent interest of Capt. Sigsbee in devising sounding apparatus and trawls.

We now come to the closing period of Alexander Agassiz's scientific life—his long years of exploration of the coral reefs of the world, for during the winter of 1885 he visited the Hawaiian Islands, studying the reefs of Oahu, Maui, and Hawaii.

For 25 years this study of the mode of formation of coral islands was to engage his rapt attention, and he was destined to wander farther and to see more coral reefs than has any man of science of the present or the past. His boyish joy upon the sight of some rare creature of the sea was something not altogether his own, for he inherited it from his father. The years of toil and care were all forgotten when he drifted in the mirrored waters above the reef and gazed downward into its world of subtle color where contrasts of olives, browns, and greens were accentuated by a butterfly-like flash of brilliancy as some fish of the coral world glided outward from the depths of the shaded cavern.

He saw more coral reefs than has any living man, and this very virtue of his exploration is its chief fault, for the study of coral reefs is a complex problem, and it can not be solved by a superficial inspection such as he was forced to make. No one realized this more fully than he did himself, but he believed that the subject should be approached by a superficial survey of all of the reefs of the world, and thus he might hope to discover places where the problem might afterwards be studied with decisive results. He aimed to point out only the broad aspects of the problem, leaving the elucidation of details to those who might follow him.

I believe that science will come to see that he succeeded in showing that Darwin's simple explanation of the formation of atolls does not hold in any part of the world. Darwin, it will be remembered, assumed that wherever we find a volcanic mountain projecting above the sea in the tropical regions corals will grow upon its submerged slopes and form a ring around it. If, then, the mountain slowly sinks beneath the sea, the corals will as constantly grow upward toward the surface, so that after the mountain has disappeared the atoll-ring of coral reefs will still remain.

Alexander Agassiz maintains, however, that atolls are formed in a variety of ways, and may develop where there has been neither marked elevation nor subsidence in modern times, as at the Great Barrier Reef of Australia, or under stationary conditions after a past

period of elevation, as in the Fiji Islands, or by dissolving away of the inner parts of an elevated limestone island, as at Bermuda, or Fulangia in Fiji, or we may have a submerged crater the volcanic rim of which may erode away to beneath sea level, thus giving a foundation for a ring-shaped coral reef.

Unfortunately the very multitude of Alexander Agassiz's observations and the somewhat confused style of his writing renders him difficult to follow. Had he enjoyed greater experience as a lecturer he might have become a clearer writer, for he constantly assumed that his readers were as familiar with the subject as himself, and that a few words would make his meaning as clear to them as to him.

It is to be regretted that of the three great writers upon coral reefs Darwin saw only one atoll, Dana sailed past many, but was permitted to land upon few, for the islands were then inhabited by dangerous cannibals, and Agassiz was compelled to cover such a vast field that certain of his conclusions, as he states himself, are still tentative; for the solution of some of the questions presented by these problems demands a more intensive and prolonged study than he was able to devote to them.

While in the Hawaiian Islands in 1885 he found that the coral reefs have repeatedly been buried under lava floes, and that the corals have again grown over the submerged lava. The reefs have nowhere been elevated more than 25 feet above sea level, but the coral sands and shell fragments have been blown upward along the mountain slopes and have formed limestone dunes, which the rains have cemented into solid rock. These wind-blown limestone ledges may be found 700 feet or more above the level of the sea.

In 1890 he published a paper showing that reef corals may become 2½ inches thick in less than seven years, his observations being based upon a study of corals that had grown upon the Habana-Key West cable.

In 1887 Alexander Agassiz was invited by the United States Fish Commission to assume the scientific direction of an expedition of the steamship *Albatross* between Panama and the Galapagos Islands, but he was unable to accept until 1891, when, from February until May, he cruised with the *Albatross* from Panama to Point Mola, thence to Cocos, Malpelo, and Galapagos Islands, and from Acapulco to the Gulf of California, making 84 deep-sea trawl hauls, soundings, and temperature observations, and in five more stations using the surface and submarine nets.

A significant feature of this expedition was due to the invention by Lieut. Commander Z. L. Tanner, United States Navy, of a self-closing net, which enabled one to obtain marine animals at any stratum of depth, and thus to determine the range in depth of marine creatures. The use of this excellent net led Alexander Agassiz to con-

clude that the floating life of the surface of the sea does not sink to a depth greater than 200 fathoms, and that the bottom forms of the deep sea do not rise more than 60 fathoms above the floor of the ocean, and that there is practically no life between 200 fathoms below the surface and 60 fathoms above the bottom. His later studies have, however, shown that these conclusions must be modified, for in the tropical Pacific surface forms are sometimes taken at a depth of about 300 fathoms beneath the surface, and although the surface animals do not commonly sink to depths greater than this, there is apparently a most interesting intermediate fauna of medusæ, etc., which are sometimes found at depths greater than 400 fathoms, and which rarely or never rise to the surface. Agassiz clearly saw the complexities and difficulties of this problem and realized that its solution can be reached only after many have labored upon it. Indeed, he himself was forced through lack of time to abandon its study to others.

A very rich collection of deep-sea forms then new to science was made by this expedition of the *Albatross*, and have been described in numerous papers in the "Bulletins" and "Memoirs" of the museum at Harvard.

The most important general result was Alexander Agassiz's discovery that the deep-sea animals of the Gulf of Panama were more closely allied to those of the depths of the Caribbean Sea than the Caribbean forms were to those of the deep waters of the Atlantic. This leads him to conclude that the Gulf of Panama was once more intimately connected with the Caribbean than the latter is with the Atlantic, and thus the Caribbean Sea was at one time merely a bay of the Pacific, and has become shut off since Cretaceous times by the uplifting of the Isthmus of Panama.

In 1892 Alexander Agassiz published his general report upon this important exploration of the Panamic region, and he concludes that the Galapagos Islands have never been connected with the mainland of America, but that the ancestors of their peculiar animals and plants were drifted over the ocean by the prevailing winds and stranded upon the shores of these remote islands. He also observed that the animals of the deep-sea are preponderatingly reddish or violet in color, and that blue-colored forms, such as are observed on the surface, are rare in the depths. This inclines him to suspect that the lingering remnant of sunlight which penetrates into the depths is red, but in view of the absence of observation he is cautious in advancing this suggestion.

Another paper of 1892 is his description of an interesting crinoid from the depths of the sea near the Galapagos Islands. This is a highly generalized form, and it is beautifully painted from life by Westergren, who accompanied him as artist upon the *Albatross*.

In 1898 and 1904 he describes the deep-sea echini found off Panama, this being his last paper upon the results of the explorations of 1891. The final report is beautifully illustrated with drawings made by A. M. Westergren.

In the autumn of 1892 his friend, Mr. John M. Forbes, offered to place at his disposal his steam yacht *Wild Duck*, a seaworthy little vessel 127 feet long upon the water line; and from January until April, 1892, he cruised in this yacht, wandering for more than 4,500 miles among the Bahamas and off the Cuban coast, engaging in the study of the part which corals have played in the formation of these islands. On this and all subsequent expeditions he was accompanied by his son Maximilian, who was his father's constant companion and friend, and who served as his photographer. The results of this voyage were published in 1894 in the "Bulletin" of the Museum of Comparative Zoology.

He concludes that the Bahama Islands are composed of æolian rock, being formed of wind-blown fragments of shells and other limestone particles of animal origin which, after being blown upward above sea level, have been agglutinated into rock by the agency of rain water. After being thus built up the islands subsided about 300 feet, and are now much smaller than they originally were, for the sea and atmospheric agencies have eroded them greatly. The present-day corals form a mere veneer over this submerged æolian rock and do not play a prominent part in forming the islands. The so-called "lagoons" of the Bahamas are merely parts of the interior of the islands which have been dissolved out under atmospheric agencies, rain, etc., and have been deepened by the action of the sea after the ocean water entered them. Hogsty Atoll he would regard as a plateau of submerged æolian rock surrounded by a rim which does not reach the surface and is protected from marine erosion by a coating of modern corals.

Five superimposed limestone terraces are seen at Cape Maysi and can be traced for a considerable distance along the Cuban coast. The lowermost of these terraces is raised only about 20 feet above sea level and is clearly an elevated coral reef, but the older and higher terraces he is inclined to regard as being of limestone covered only by a mere veneer of corals or containing only a few scattered coral heads and not true elevated coral reefs.

The peculiar flask-shaped harbors of Cuba with their narrow entrances and broad lagoons interested him greatly, and he decided that when the land was elevated these depressions had been leached out in the limestone by the action of streams in the drainage areas of the valleys, and when the land afterwards sank the broad valleys were submerged, with only a deep narrow entrance connecting them with

the sea. Yumuri Valley would constitute just such a harbor were it submerged beneath the sea.

This study of the reefs of Cuba and the Bahamas naturally led him to renew his observations in Florida and to visit the Bermudas. He saw the Bermuda Islands in March, 1894, and in December of the same year he chartered a tug and steamed along the Barrier Reef of Florida.

He found that, in common with the Bahamas, the Bermudas consist of æolian limestone. In places the interior of these islands as dissolved away by the action of rain water rendered acid by decomposing vegetable matter, and thus depressions were formed in the central parts of the islands. Then when the islands sank the sea broke through the rims and filled the lagoons, afterwards deepening them by its scouring action.

Thus the Bermudas have assumed an atoll-like shape, but their contour is not due to corals. Indeed, there are but few corals at Bermuda, and these form a mere veneer over the sunken æolian ledges. The so-called miniature atolls are mere pot-hole basins which have been scooped out by wave action in the æolian rock, and their rims are never more than 18 inches high, and consist of a wall of æolian rock covered by a coating of serpulæ, algæ, and corallines, which enable them to withstand the wearing action of the sea. Thus Darwin's theory of coral reefs can not explain the conditions seen in the Bahamas and Bermudas.

The results of his study of the Florida Reef were finally published in 1896, in cooperation with Dr. Leon S. Griswold. Agassiz concludes that the Marquesas of Florida are not an atoll, but inclose a sound that has not been formed by subsidence, but by the solvent and mechanical action of the sea. Thus the Marquesas are similar in their geological history to other sounds back of the line of the Florida Keys.

He found an elevated reef extending along the seaward face of the Florida Keys from Lower Matacumbe to Soldier's Key. We now know, however, that the elevated reef actually extends from the southern end of Big Pine Key to Soldier's Key. Agassiz believed that the oolite limestone back of the elevated reef and along the mainland shore of Key Biscayne Bay was æolian rock; but Griswold decided that it was only a mud flat which had been formed beneath the water, and afterwards elevated. Later studies have shown that Griswold was right.

In 1895 he instituted a study of the underground temperature of the rock walls of the Calumet and Hecla mine, and found that the increase is only 1° F. for every 223.7 feet as we descend. His deepest temperature observation was 4,580 feet beneath the surface of the ground.

He had now seen all of the coral reefs of the Atlantic and turned his attention to the exploration of the Pacific. In April and May, 1896, he cruised along the Great Barrier Reef of Australia in the little steamer *Croydon*, which he chartered from the Australian United Steam Navigation Co., Capt. W. C. Thomson being in command. The voyage began at Brisbane in April, extended northward to the Hope Islands, and ended at Cooktown in May. Unfortunately, he had come to Australia in the height of the trade-wind season, and the almost constant gale greatly hindered the work of his expedition. Indeed, during more than a month of cruising he could spend only three days on the outer reefs, and the dredging and study of marine life which he had hoped to carry out were practically abandoned.

He concluded that the many islands and submerged flats off the Queensland coast were once connected with the mainland, but have been separated from the continent by erosion and denudation. After the formation of these flats and islands corals grew upon them. The recent reefs have been elevated at least 10 feet, and do not owe their contours to subsidence, yet they form true atolls. The inner channels of the Barrier Reef are maintained free of corals by the great amount of silt held in suspension in the water or deposited to form a blue mud over the bottom. Thus there appears to be nothing in the Great Barrier Reef region to lend support to Darwin's theory of coral reefs.

A tangible result of this expedition was the enriching of the museum at Cambridge by a great collection of Barrier Reef corals gathered under Alexander Agassiz's auspices by H. A. Ward.

His experience in Australia taught him to avoid the trade-wind season and henceforth his expeditions to coral seas were timed so that he cruised among the reefs in the late spring and early summer months when the trades have died out into the long hot days of calm which precede the coming of the hurricanes. This interval when the torrid sea is sleeping gave him the opportunity to land on many a jagged shore that defied approach at other seasons. He then could wade through the still waters over the coral reefs, and unravel at his will the secrets of the atolls, composed as they are of wave-tossed fragments that once were shells of mollusks or skeletons of creatures of the reefs. His overmastering interest carried him to the shores of hundreds of these distant atolls where the coco palm, the *Pandanus*, and the fishes of the reef afford the only sustenance for man, where there are no hills or streams and the land is only a narrow strip across which one hears constantly the roar of heavy breakers.

These years of cruising accentuated his already predominant self-reliance, for the commander of a marine expedition must needs be an autocrat by profession. He was accustomed to command and to be obeyed and his relation to the Harvard Museum during these later

years was in miniature similar to that of Bismarck to the German empire. Indeed, there was a strange physical and mental resemblance between Alexander Agassiz and Bismarck. Fearless, resolute, quick to anger, definitely purposeful and full of resource, they were closely akin in character, and indeed there seemed much in common between the two, for during the course of his long and honored life Alexander Agassiz had been granted many interviews with exalted personages, but his meeting with Bismarck was the only one to which he delighted to refer. Alexander Agassiz was a colossal leader of great enterprises, fully as much as he was a man of science.

The cold winters of Cambridge were intolerable to him, and each year from 1875 until the close of his life he sought a more genial climate. Upon these pleasure excursions he visited Mexico, Central America, the West Indies, India, Ceylon, Japan, the readily accessible parts of Africa, and every country in Europe. He never went far into the arctic regions, although he saw the midnight sun at North Cape and visited the Aleutian Islands. Upon all excursions of the last 20 years of his life his constant companion and friend was his son Maximilian.

In 1896, in collaboration with Dr. W. McM. Woodworth, he published a paper upon the variations of 3,917 specimens of the medusa *Obelia* (*Eucope*), in which the authors show that aberrant specimens of *Obelia* are very common. This paper is illustrated by interesting photographs made from life by Dr. Woodworth. This is one of the last of the studies published by him from his Newport laboratory, the latest one being in 1898 upon the scyphomedusa *Dactylometra*.

From November, 1897, to January, 1898, he cruised among the Fiji Islands in the little steamer *Yaralla*, chartered from the Australian United Steam Navigation Co. and under the command of Capt. W. C. Thomson.

Dana had stated that the coral reefs of the Fiji Islands were typical examples of the theory of Darwin, and Agassiz was greatly surprised therefore to find the clearest evidence of elevation, for in some places, as at Vatu Vara Island, the late Tertiary limestones are lifted more than 1,000 feet above the sea. This great elevation, which is so evident in numerous places among the Fiji Islands, probably took place in later Tertiary times, and since then the islands have been greatly eroded and reduced in size, deep valleys being cut into their mountain slopes and many of the islands having been washed away by the tropical rains, leaving only a submerged flat. The coral reefs that grew around the shore line of the islands still remain after the islands have washed away, and thus the living reefs now mark the contours of the islands as they were. The currents flowing in and out of openings in the reef rim have deepened the lagoons, but nevertheless there are many coral heads growing in the lagoon of every coral atoll.

He saw that the coral reefs which grew around a volcanic mountain remain after the mountain has washed away, and thus an atoll is formed without the agency of subsidence. In other cases, as at Fulangia, there was once an elevated coral limestone island lifted above sea level. Then rain water and atmospheric erosion leached out depressions in its central parts and finally the sea entered, forming a lagoon surrounded by a ring of detached islets of elevated limestone. In other cases the crater rims have washed away and a ring of coral reefs now marks the site of the old volcanic ridge.

According to Agassiz the coral reefs of to-day in the Fiji Islands form only a crust of moderate thickness upon a base of old limestone or volcanic rock. The present corals form only fringing reefs along the shores, and the contours of the atolls and barrier reefs are thus due to causes which acted at the time when the islands were elevated late in the Tertiary period.

In so great an archipelago as that of the Fijis with more than 270 islands there must be many details of reef formation, the elucidation of which requires more prolonged study than Agassiz was enabled to devote to them in his visit of less than three months; for example, he was puzzled to explain the great thickness—1,000 feet and more—of the elevated limestones; for reef corals do not grow at depths greater than about 120 feet. Could these enormous accumulations have been formed by coral reefs during a period of slow subsidence, as Darwin had assumed, or were they merely the talus of broken fragments which had rolled down the seaward sides from the outer edges of the reef, or were they formed by a slow accumulation of limestone fragments and shells of marine creatures other than corals which had lived upon the bottom more than 1,000 feet beneath the surface and gradually built up a vast mass of limestone, as was the case with the great submerged Pourtalès Plateau off the Florida coast? He had in mind the fact that even in the richest coral-reef regions the masses of broken shells and fragments of calcareous plants are commonly vastly greater than the bulk of the corals, for the corals grow only here and there over the limestone flats, and flourish luxuriantly only on their seaward slopes.

Were such a reef to form during a long period of slow subsidence, and then become elevated above the sea, we should find only an occasional coral here and there imbedded in a great mass of limestone. This is the appearance presented by some of these elevated limestone cliffs of the Pacific islands, while others appear to be walls of non-coral-bearing limestone capped above with a crust of corals. In many cases, however, the corals they once contained have disappeared and been replaced by calcite or dolomite. These elevated limestones soon become very hard when exposed to the atmosphere, for they become coated by a dense veneer which rings with a clinkerlike sound

when struck with a hammer. One sometimes finds shells of the giant clam, *Tridacna*, imbedded in this hard limestone and elevated above the sea, and yet the nacre of the shell is still white and polished, thus proving that the rock was elevated only recently, and certainly not longer ago than in late Tertiary times.

Altogether the most interesting problem raised by Alexander Agassiz's researches in the Pacific is the question of the relation between these elevated Tertiary reefs and the growing coral reefs of today, and it still remains unsolved, despite the careful studies made by Mr. E. C. Andrews, whom Alexander Agassiz sent to the Fiji Islands especially to study this problem, for Andrews's investigation has merely served to show that the subject is very complex and can not be solved until prolonged study of certain favorable localities has been completed.

From August, 1899, until March, 1900, Alexander Agassiz had for the second time the scientific direction of the *Albatross*. Commander Jefferson F. Moser, United States Navy, was in command and the cruise began at San Francisco and extended across the tropical regions of the Pacific to the Ladrone Islands and thence northward to Japan. On this great cruise the *Albatross* visited the Marquesas, Paumotos, Society, Cook, Nieue, Tonga, Fiji, Ellice, Gilbert, Marshall, Caroline, and Ladrone Islands, steaming many thousands of miles in and out among the atolls.

From San Francisco the vessel steamed 4,000 miles straight to the Marquesas, making many soundings and trawl hauls which led to the discovery that there is here a great basin between 2,500 and 3,000 fathoms deep, the bottom of which is covered with manganese nodules and the teeth of extinct sharks. It was an impressive sight to see the great trawl bring up tons of the manganese nodules looking like gritty brown potatoes, and all nearly as cold as ice, for the temperature of the deep floor of the ocean here was less than 3° F. above freezing. Despite the heat of the tropic sun beating upon our deck our hands stung with the cold as we felt among the mass of nodules and cracked them open to discover the inclosed nucleus of pumice, the encrusted ear bone of an extinct whale or a shark's tooth imbedded in the soft brown rock. Some of these shark's teeth were so large that the shark itself was probably more than 100 feet long. A deep submarine area far greater than that of the United States is covered thickly by these manganese nodules and sharks' teeth, and Alexander Agassiz named it the "Moser Deep," in honor of the commander of the *Albatross*.

Very little animal life was found, either floating in the sea or on the bottom, over this vast desert of manganese nodules.

The chief result of this expedition was the discovery that a widespread elevation of the Pacific islands occurred in late Tertiary times.

The Hawaiian, Paumotos, Society, Cook, Nieue, Tonga, Fiji, Ladrone, and Caroline Islands all show elevated coral or limestone reefs, but there are no visible indications of elevation in the Marshall or Gilbert Islands where the underlying rock is not lifted above the sea. Makatea in the Paumotos may have been an atoll which was elevated about 230 feet above the sea and with a lagoon basin in the center sunken about 70 feet below the encircling ridge. It is possible, however, that this central concavity may have been formed by solution after the island was raised above the sea, and that the island was not originally an atoll.

The lagoons of the Pacific atolls were found to be usually from 13 to 20 fathoms deep, and to be quite thickly studded with submerged rocks consisting of Tertiary limestone incrusted with modern corals.

The atoll contours are due to a coordination of complex conditions, erosion, currents, silt, etc., which determine the place and rates of growth of the corals; and not to subsidence, as was postulated by Darwin.

The modern coral reefs are, according to Agassiz, distinct from the Tertiary limestones, and form a mere crust upon a base of lava or of old limestone.

A notable act of the expedition was the bringing up of the deepest trawl haul ever made, this being from a depth of 4,173 fathoms, 75 miles east of Tonga Tabu. Siliceous sponges were found here under an ocean almost as deep as the crests of the Himalayas are high.

In Bora Bora, of the Society Group, he found a broken ring of sandy coral islets covered with coco palms, and encircling the shallow waters of the lagoon, out of the center of which there arises the towering mass of the basaltic cliffs of the island. The sight of this old volcano, now sleeping and encircled by its palm-crowned atoll ring, so impressed Alexander Agassiz that he employed Mr. G. W. Curtis to make a survey, and to construct a detailed model of the island for the museum at Harvard.

As one goes westward over the tropical Pacific the coral heads upon the reefs become larger and larger, those of the Paumotos being small and stunted, while those of the Great Barrier Reef of Australia are the largest in the world.

Alexander Agassiz had now seen nearly all of the coral islands of the Pacific, and he at once turned his attention to the Indian Ocean, cruising among the atolls of the Maldive Islands from December, 1901, to January, 1902. For this purpose he chartered the steamer *Amra* from the British India Steam Navigation Co., William Pigott, R. N. R., in command. He steamed more than 1,600 miles among the islands, making more than 80 soundings. Mr. J. Stanley Gardiner, M. A., had only recently explored the Maldives, and his account of their mode of formation was published before that of Agassiz.

Both Gardiner and Agassiz agree that there is evidence of recent elevation in the Maldives, and that conditions which are operating at the present day are determining the shape of the atolls. Shifting sandbars play a considerable rôle in determining the contours of the atolls, some of them being mainly rings of sandbars inclosing a lagoon, as in the Gilbert Islands. No elevated Tertiary limestones were seen, but the modern coral reef is in places now above the sea. In essential respects Gardiner and Agassiz are in accord, and both decide that Darwin's theory is not applicable to the Maldives. They differ, however, in the conception of a "perfect atoll," and in their opinions of some of the causes which have led to the deepening of the lagoons, but the discussion of these matters would be unprofitable in this place.

Dr. Henry B. Bigelow was an assistant upon this expedition and wrote a report upon the medusæ.

After his return from this expedition Alexander Agassiz was not suffered to remain long at rest, for once again, for the third and last time, he was given charge of the *Albatross*. The *Albatross* left San Francisco on October 6, 1904, and steamed to Panama. Thence to the Galapagos Islands, then to Aguja Point and Callao on the Peruvian coast, and then to Easter Island, from which she returned to the Galapagos, only to again venture out over the Pacific to Manga Reva, then back to Acapulco, and home to San Diego, where she arrived in March, 1905. Lieut. Commander L. M. Garrett, United States Navy, was in command, and they crossed and recrossed the Humboldt current four times, cruising more than 13,000 miles, making 160 deep-sea soundings and 280 pelagic hauls. The expedition ranged over the largest uninterrupted area of ocean in the world. Prof. C. A. Kofoid collected the protozoa and Dr. Henry B. Bigelow the medusæ, while the coral reefs, oceanography, and echinoderms were studied by Alexander Agassiz.

Interesting photographs of the great stone images of Easter Island were obtained, and it was found that Manga Reva is a barrier reef island with an eroded volcanic center.

A remarkable result of the expedition is the discovery that the cold Humboldt current, which flows northward along the western coast of South America from the Antarctic to the equator, is a great bearer of pelagic life teeming with medusæ, salpæ, and all manner of floating creatures, both on the surface and in its depths; but in the outer Pacific beyond the western edge of this great current we find a vast area almost barren of life. Also the bottom under the Humboldt current is crowded with organisms, whereas there is a sparsely inhabited submarine desert to the westward of the western edge of the current. The effect of this current upon the distribution of pelagic

life is most clearly described by Henry B. Bigelow in his account of the medusæ of this expedition.

This was Alexander Agassiz's last great scientific expedition, although in 1908 he made a brief visit to the Florida Reef, and from February until March, 1907, he cruised through the West Indies from Porto Rico to Grenada in the chartered yacht *Virginia*. Dr. Henry B. Bigelow was his scientific assistant, and many pelagic hauls were made, but the region was found to be almost barren of floating life. This is an extraordinary fact, and it applies at present to the whole vast region of the West Indies, thus from 1877 until 1898 the region of the Tortugas, Fla., was noted for the variety and richness of its floating life, but since that time the pelagic animals have become rarer year by year until at present the region is almost a desert sea.

In August, 1907, he presided over the meeting of the Seventh International Zoological Congress at Boston, and his presidential address is an account of the publications which had resulted from his many expeditions, and the reports of those to whom he had sent collections. These include the most noted specialists in all of the highly civilized countries of the world.

In the winter and early spring of 1908 he visited the equatorial lake regions of Central Africa, the expedition being mainly a pleasure trip.

Between 1907 and 1909 he published five papers upon Pacific echini with Dr. Hubert Lyman Clark as joint author, and other papers of this series are still to appear.

In common with all students of pure science in our country, Alexander Agassiz was far more highly appreciated abroad than he was at home, for in our country practical applications and the invention of mechanical devices compass nearly all that the general public cares for science, and indeed our Republic is without means to confer honors upon its scientific men. Thus while he was an honorary member of all of the great scientific societies of Europe and had been recogized officially by the Republic of France and the German Emperor, only one American university (his alma mater) conferred upon him an honorary degree.

In 1898 he was made an Officer of the Legion of Honor of France and in 1902 a Knight of the Order of Merit of Prussia. He was a foreign associate of the Academy of Science of the Institute of France, the only American associates of that time being Agassiz and Newcomb. He was foreign honorary fellow of the Royal Society of Edinburgh, foreign member of the Royal, Linnean, and Zoological Societies of London, honorary member of the Royal Microscopical Society of London, and honorary member of the academies of Berlin, Prague, Göttingen, Leipzig, Munich, Manchester, Vienna, Upsala, Stockholm, Copenhagen, Liège, Moscow, Rome, Bologna, Geneva, Mexico, etc.

He received the honorary degree of LL. D. from Harvard in 1885 and from St. Andrews, Scotland, in 1901; Ph. D. from Bologna in 1888; and honorary Sc. D. from Cambridge in 1887.

In 1878 he was awarded the Prix Serres by the Paris Academy, being the first foreigner to be thus honored, and in 1909 he received the Victoria research medal of the Royal Society of London.

After the publication of the results of the Maldive and eastern Pacific expeditions, one great and final task lay before him. This was to present a summary of the results of his 25 years of study of the coral reefs of the world. Five years would have been required for the preparation of this crowning work, which would have borne the same relation to his coral-reef studies that his "Three Cruises of the *Blake*" did to his early deep-sea work—an epitome of the whole subject. For 82 years the Agassiz father and son had been active leaders in science, and he hoped for five more years of productivity.

But this was not to be. He had for several years been suffering from an impairment of the circulation and had retreated for rest and recreation to the genial climate of Egypt and southern Europe.

He was returning from England in the steamship *Adriatic*, and never did he appear to be in happier mood than upon the night of the 26th of March, 1910; but on the morning of the 27th he failed to appear, and when his son Maximilian entered his father's cabin it was seen that he had fallen into his last long sleep. Many a guarded secret had the ocean revealed to him, and it was fitting that far from the sight of land with only the waves around there came to him the mystery of death.

When I was young and struggling his hand befriended me and his great mind gave direction to the thought of the life I have led, and I think upon his spirit with gratitude and reverence, for he was my master in science.

NOTE.—A list of the principal scientific works of Alexander Agassiz accompanies Mr. Mayer's reprint of the above paper. "Including minor publications, he was the author of at least 248 titles. See Charles W. Eliot, in Harvard Graduates' Magazine, vol. 18, p. 603. June, 1910."—EDITOR.

RECENT WORK ON THE DETERMINATION OF SEX.[1]

By Leonard Doncaster, M. A.,
Fellow of King's College, Cambridge.

[Note.—This paper was written in 1909, and much important work on the subject has appeared since. It has only been possible to refer in footnotes to a few of the more important of these papers. The additional notes and references are inclosed in square brackets [ ]. It will be seen that some of the opinions expressed may require modification in the light of our fuller knowledge.—L. D. April, 1911.]

At the Dublin meeting of the British Association the sections of zoology and botany devoted a morning to a joint discussion on the determination of sex. Some account of the opinions expressed has appeared in reports of that meeting.[2] As in all discussions on this subject, the speakers were divided into two groups, holding opinions which at first sight appear irreconcilable. On the one hand there was the school which maintains that sex is a property of the germ cells and that after fertilization, if not before, the egg is irrevocably committed to one or the other sex; on the other there were representatives of the influential body of biologists who prefer the view that sex can be influenced by external conditions and that the sex of any individual is the result of a combination of forces, some tending in one direction, some in another. Not many years ago the latter was the prevalent opinion; it was supposed that the fertilized ovum was potentially bisexual, maleness being introduced by the spermatozoon and femaleness by the egg, and that the sex of the developing organism was determined by a variety of factors, the resultant of which decided to which side the balance should incline. This idea was supported by experiments on feeding the larvæ of insects, frogs, etc., in which it appeared that insufficient diet led to a higher proportion of males than when the creatures were abundantly fed. But critics have always pointed to the fact that these results might be explained by differential mortality or other circumstances not allowed

[1] Reprinted by permission, with author's additions and corrections, from Science Progress, London, No. 13. July, 1909, pp. 90–104.
[2] Nature, Oct. 22, 1908, vol. 78, p. 647.

for by the experimenters; as we shall see, there is such a mass of evidence accumulated on the other side that this idea is now largely abandoned by biologists.

But although the doctrine that sex may be influenced by the environment of the embryo or larva is largely discredited, a considerable body of evidence has been brought forward to show that influences acting on the parents, particularly on the mother, before fertilization, may affect the sex of the offspring; this idea is not open to the objections which appear fatal to the older view. Two of the most convincing pieces of work supporting this conclusion are those of Issakowitsch on the Daphniidæ[1] and von Malsen on *Dinophilus*.[2] Issakowitsch worked with the parthenogenetic females of *Simocephalus*, von Malsen with *Dinophilus apatris*, in which the eggs are fertilized; each found that differences of temperature caused differences in the proportion of males produced and both ascribed the difference to changes in the nutrition of the mother. Maupas[3] and Nussbaum[4] made somewhat similar statements about *Hydatina senta*, in which all females are from birth either male producing or female producing; but according to them the sex of the offspring of a parthenogenetic female is determined by the conditions of temperature or nutrition to which that female is subjected in the parental uterus. Punnett[5] denies that temperature or nutrition has any effect in the case of *Hydatina* and says that some stocks give rise to many arrhenotokous (male producing) individuals, others to few or none. So it seems not impossible that in this case, at least, the evidence for the influence of environment may not be as good as it appears at first, and that some such cause as differential mortality may bring about the results observed.[6]

The idea that various external circumstances may influence the proportion of the sexes does not rest only on experiments on invertebrates; there is a considerable mass of statistics pointing in the same direction in the higher vertebrates, including man. In these cases the number of young produced by one pair is relatively small, and in most cases the evidence takes the form of figures drawn from a considerable population. The differences due to altered environment or other circumstances usually amount to only a few per cent; but if they are consistent in a large population they must be taken into account in any theory of sex determination. There is a vast number of papers of this kind, suggesting that a great variety of external cir-

[1] Biol. Centralblatt, vol. 25, 1905, p. 529; and Arch. Mikr. Anat., vol. 69, 1906, p. 223.
[2] Arch. Mikr. Anat., vol. 69, 1906, p. 73.
[3] Comptes Rendus, vol. 111, 1890, pp. 310, 505.
[4] Arch. Mikr. Anat., vol. 49, p. 227.
[5] Proc. Roy. Soc. B., vol. 78, 1906, p. 223.
[6] See Whitney, Journ. Exp. Zoo., vol. 5, 1907, p. 1, for experiments on *Hydatina*, explaining Maupas's results. [Also Shull, American Naturalist, Mar., 1910; and Journ. Exp. Zool., vol. 8, 1910, p. 311; vol. 10, 1911, p. 117.]

cumstances may affect the percentage of the sexes among the offspring born; among these we may choose a few of the more recent as examples of the kind of result obtained. Pearl[1] shows that of over 200,000 births in Buenos Aires, the proportion of males is significantly greater when the parents are of different racial stocks than when they are of the same. The difference ranges from about 1 per cent to about 5 per cent, but is always on the same side. Punnett[2] finds that in London the proportion of males is lowest in the poorest portion, highest in the wealthiest, and intermediate in the intermediate portion. The males per 100 females were, respectively, 99.5, 102.2, and 100.7; but he points out that these differences are probably wholly explicable on the grounds of differential infant mortality, birth rate, and probably marriage rate. Heape,[3] from statistics of over 17,000 greyhounds, concludes that whilst males are always considerably in excess (averaging 118.5 to 100 females), the proportion is noticeably higher in the season during which fewest pups are born. In a later note in the same volume (loc. cit., p. 201) Heape gives some curious figures with regard to canaries, showing that in one aviary (out of 200 birds hatched) the ratio of males was about 77 to 100 females, while in another (out of 68 birds) the males were in the ratio of 353 to 100 females. Evidence is given that these differences are not ascribable to mortality; Heape supposes that in both cases the proportion of the sexes is due to a selective action of conditions on the ova which are matured. He assumes that ova bear either maleness or femaleness, and that some forms of environment favor the maturation of one kind, some of the other. The same explanation is applicable to other cases in which the proportion appears to be influenced by external circumstances.

It appears therefore that the idea that the proportion of the sexes may be influenced by conditions acting on the parents is not inconsistent with the hypothesis that the germ cells bear only one or the other sex, as long as the primary germ cells do not all come to maturity. This is the case at least in the females of the higher vertebrates; and it is from them that the greatest amount of evidence in this direction has been obtained. Russo[4] has recently maintained that treatment with lecithin causes an increase in the number of female ova matured in the rabbit and believes that he can distinguish the male from the female eggs in the ovary. He admits, however, that the families in his tables are selected and it seems that the differences

[1] Biol. Bulletin, vol. 15, 1908, p. 194.
[2] Proc. Camb. Phil. Soc., vol. 12, 1903, p. 262.
[3] Ibid., vol. 14, 1907, p. 121. [See also Heape, 'The Proportion of the Sexes produced by Whites and Colored People in Cuba.' Phil. Trans. Roy. Soc. B. 269, p. 271–330 (vol. 200, 1909).]
[4] Atti Acad. Lincei, vol. 16, 1907, p. 362.

he observed between the two kinds of eggs were probably due to degenerative changes in some.

One of the first writers to maintain that the ova bear either maleness or femaleness was Beard,[1] who suggested that originally there had also been two kinds of spermatozoa, but that one has disappeared in most animals, remaining in a functionless condition in such cases as *Paludina* and *Pygæra*, which give rise to the two kinds. His paper is somewhat speculative; but there is a steadily accumulating body of proof that the sex is irrevocably decided at least from the moment of fertilization. This belief is supported by a number of different facts. It has long been known that in man "identical twins" are always of the same sex, i. e., that when twins are born so like one another that they are distinguished with difficulty, they are never of different sexes; in these cases the twins are produced by the division of one fertilized ovum and during fœtal life are enveloped in the same membrane.[2] Twins produced by the simultaneous development of two ova are not more like each other than other brothers and sisters, and are frequently of different sexes. A similar but perhaps even more conclusive case is provided by the parasitic Hymenopterous insects in which there is embryonic fission. Silvestri[3] has investigated two such insects, *Litomastix* and *Ageniaspis*. In each the flies lay their eggs in the eggs of other insects, and at the close of segmentation the embryonic cells become clustered into groups, each of which produces a separate embryo. In *Litomastix*, the number of larvæ so produced may be about 1,000; in *Ageniaspis*, 10 to 20; but if only one egg be laid by the parasite in the egg of the host, all the flies which hatch are of the same sex. Similar cases of embryonic fission in parasitic Hymenoptera have been described by Marchal,[4] with the same results in respect of sex.

Another line of argument tending in the same direction is drawn from animals which have more than one kind of egg, in which eggs of one kind produce males, those of the other females. Some such cases occur among parthenogenetic species, e. g., the rotifer *Hydatina*, and *Phylloxera* among insects; but in other animals both kinds of eggs require fertilization, and the larger always yield females, the smaller males. This has been shown to be the case in *Dinophilus apatris* by von Malsen (loc. cit.), in the mite *Pediculopsis* by Reuter[5] and is suspected by Montgomery in a spider.[6] In these cases there can be no question of modifying the sex by external circumstances after the egg is fully formed; but it might perhaps be maintained that

[1] Zool. Jahrbücher, Anat., vol. 16, pp. 615 and 703, and other papers.
[2] See Galton, Human Faculty, 2d ed. (J. M. Dent), p. 156.
[3] Annali R. Scuola Agric. Portici, vol. 6, 1906, and Bollettino R. Scuola Ag., vol. 3, 1908.
[4] Arch. Zoo. Exp. und Gen. (4), vol. 2, p. 257.
[5] Festschrift für Palmén, 1905–7, vol. 1.
[6] Journ. Exp. Zoo., vol. 5, p. 429.

the very fact of one kind of egg being larger and having more yolk was the cause of its becoming a female.

Probably the most convincing proof that the sex is irrevocably determined from the beginning of development is obtained from the study of cases in which the same eggs may be either parthenogenetic or fertilized. The best-known example is the honeybee. In this insect, as is well known, unfertilized eggs yield males and fertilized eggs females, either queens or workers according to the treatment to which the larva is subjected. This statement has several times been denied, but the facts are overwhelmingly in favor of its truth in the hive bee; and numerous other examples are now known among the Hymenoptera. As examples, we may quote the work mentioned above by Silvestri on *Litomastix* and *Ageniaspis*, in which the developmental processes are precisely similar whether the egg be fertilized or not; but in the first case females are produced, in the second, males. Similarly Wassiliew [1] found in the parasitic Hymenopteran *Telenomus* that all eggs laid by virgin females became males, while those of fertilized females yielded about 80 per cent of females. It may be assumed that the remaining 20 per cent received no spermatozoon. In instances of this kind it is perfectly clear that the sex is definitely determined at fertilization; but it can not be supposed that the egg bears irrevocably one sex or the other before the entrance of the spermatozoon. As will be seen below, it has been assumed by some writers on the subject that the egg before fertilization bears maleness, and that the female element is introduced by the spermatozoon; but it is at least conceivable that the unmatured egg potentially bears both sexes and that the presence of the spermatozoon determines which sex-determinant shall become effective.

Before leaving this part of the subject it should be noticed that there are a number of Hymenoptera which are anomalous in this respect. In ants and wasps workers sometimes lay eggs, said always to yield males,[2] so falling into line with the bee; but Reichenbach [3] states that the workers of a species of ant produced workers, except at the time of year when males are normally produced in the nests, when males appeared. It is, of course, possible that there was error of observation,[4] but there is no doubt that in the sawflies some species produce males, a few, mixed broods, some only females from unfertilized eggs. The case of the common *Nematus ribesii* is remarkable; males are usually yielded by virgin eggs, but a small proportion of females (less than 1 per cent) is generally obtained. These may pos-

[1] Zoo. Anzeig., May, 1904.

[2] Field, Biol. Bull. vol. 9, 1905, p. 355; Marchal, Arch. Zoo. Exp. und Gen. (3), vol. 4, p. 1.

[3] Biol. Centralblatt, vol. 22, p. 461.

[4] [Reichenbach's observation has since been confirmed by Crawley and Donisthorpe, Proc. Entom. Soc. London, 1910, vol. 5, p. 67.]

sibly be introduced by accident, since the species is so abundant. The writer at one time supposed that there were two kinds of eggs, one requiring fertilization and yielding females, the other developing into males without being fertilized. But more recent experiments (made with the help of Mr. A. C. Tunstall, and not yet sufficiently extensive) do not support this idea. Out of two broods—one of 58 eggs, the other of 102—53 and 67 male pupæ or adult larvæ were reared, which clearly indicates that the absence of females was not caused by their dying off; for among the eggs of fertilized females at least 50 per cent commonly yield females. It was not possible in these experiments to hatch out the flies, but the size of the adult larvæ or pupæ is an almost unfailing criterion of the sex. It seems probable therefore that *Nematus ribesii* must be placed in the same category with the bee. The gallflies (Cynipidæ) offer another anomalous instance, for in them there are two generations in the year, one of which consists of both sexes, of which all the eggs are fertilized and yield a parthenogenetic generation consisting wholly of females. The eggs of the latter yield both males and females, and the writer has shown that the male-producing eggs undergo maturation; the female-producing do not.[1]

One more point must be mentioned here. In bees some hives produce a large proportion of gynandromorphic individuals, which are irregular mixtures or mosaics of male and female characters. Von Siebold[2] described such a case, and found that all the "zwitterbienen" were in worker cells, the drones being all pure. The hive was hybrid from Italian stock crossed with black; the drones were of the Italian type, the workers mixed. Two possible explanations may be hazarded: First, that the egg which develops into a gynandromorph has begun to segment, and that the male pronucleus conjugates with one of the segmenting nuclei; or, secondly, that the male pronucleus conjugates with one (probably the second) of the polar nuclei, and that both the zygote nucleus so produced and the female pronucleus take part in the development. Of these, the second is perhaps the more likely hypothesis.

It has been mentioned above that Beard was one of the first to suggest that the germ cells bear the determinant for one or the other sex; it now remains to discuss the evidence which has since accumulated in favor of that hypothesis. It has received support on several very distinct grounds. We may take, first, the cytological results with which the names of several American investigators are chiefly associated, although much similar work has been done in Germany, France, and elsewhere. To give an at all adequate account of the

[1] [Proc. Roy. Soc. B. 82, 1910, p. 88, and second part of the same paper to be published in Proc. Roy. Soc. shortly.]

[2] Zeit. Wiss. Zoo., vol. 14, p. 73.

numerous papers on spermatogenesis and oogenesis, which have led to the hypothesis that the sex determinant is a visible chromosome-like body, would occupy more space than is available, so we will take the work of E. B. Wilson as typical, although similar phenomena had been already observed by Paulmier, McClung, Miss Stevens, and others. Wilson,[1] working at a number of genera of Hemipterous insects, finds that in the unreduced germ cells of the female there are always an even number of chromosomes, two of which (idiochromosomes) are frequently distinguishable from the remainder by their size. In the males there is either an odd number, owing to the absence of one idiochromosome, or one idiochromosome has the size which it has in the female, while the other is vestigial. At the reducing division the number is halved; when both idiochromosomes are present they pair together and become separated into different daughter-nuclei; when in the male there is only one, it passes to one end of the spindle and the other is left without one. In this way it comes about that all the eggs appear alike as regards their chromosome groups, but in the male there are two kinds of spermatozoa, an idiochromosome being present in the one half, but absent or vestigial in the other half. Wilson was therefore led at first to suggest that the spermatozoon determined the sex, sperms with the "accessory" chromosome giving rise to females, those without it to males. Later[2] he modified this hypothesis in favor of one which will allow the sex determinants to be regarded as Mendelian characters, femaleness being dominant over maleness. The two idiochromosomes in the female are regarded as male bearing and female bearing, respectively, so that some eggs after maturation bear maleness, others femaleness. The single idiochromosome in the male is male bearing, and there is supposed to be selective fertilization; so that a male-bearing sperm can conjugate only with a female-bearing egg and a sperm bearing no sex determinant (idiochromosome) with a male-bearing egg. If femaleness is dominant, all fertilized eggs having two idiochromosomes will become females, those having only one, males. It is interesting that breeding experiments with Lepidoptera, which will be mentioned below, led the present writer[3] to formulate an almost exactly similar hypothesis at almost the same time. But it will be seen that later experiments with moths suggest that a slightly different explanation of the facts is possible.

[1] "Studies on Chromosomes," i, ii, iii, and iv, Journ. Exp. Zoo. 1905, 1906, 1909. Also several papers in Science, 1905–7, etc., especially 1909, vol. 29, p. 53, a review of the whole subject. It should be mentioned that the accuracy of Wilson's observations has been questioned by several investigators, e. g., Foot and Strobell, Amer. Journ. Anat., vol. 7, 1907, p. 279.

[2] "Studies on Chromosomes," iii, Journ. Exp. Zoo., vol. 3, 1906. No. 1. For a still later suggestion of Wilson's see footnote near the end of this article.

[3] Doncaster and Raynor, Proc. Zoo. Soc. 1906, vol. 1, p. 125.

The essence of Wilson's hypothesis is that the sex determinants behave as Mendelian characters, segregating from one another in gametogenesis (at the reduction division), that femaleness is dominant, and that there is selective fertilization; so that a male-bearing egg is fertilized by a female-bearing spermatozoon. Suggestions closely similar to these were put forward by Castle [1] on quite different grounds in 1903. Castle collected a quantity of evidence from breeding experiments and from what is known with regard to parthenogenetic reproduction. He supposed that every individual arising from a fertilized egg is heterozygous (hybrid) in respect of sex, and that segregation takes place at the second maturation division, so that half the gametes bear maleness, half femaleness. Male-bearing eggs conjugate with female-bearing spermatozoa and vice versa; but dominance is alternative, so that roughly half develop into each sex. In most parthenogenetic animals only one polar body is produced in eggs which will not be fertilized; in these cases femaleness is always supposed to dominate. Since with only one polar division no segregation takes place, the offspring are females. If in a parthenogenetic species two polar bodies are produced the offspring are commonly males, since the female determinant is supposed to be eliminated with the second polar nucleus. A further valuable suggestion was that the male and female determinants might be "coupled" with certain body characters, either invariably—so explaining sexual dimorphism—or frequently, by which is explained the general association of one variety with one sex, another with the other, in the offspring of certain crosses. Wilson has since [2] observed coupling of ordinary with idiochromosomes, which may be connected with this phenomenon.

Castle's suggestive paper has stimulated much work on the maturation of parthenogenetic species, but his hypotheses do not always hold good. For example, it is now known that parthenogenetically produced males in the Aphides arise from eggs which have only one maturation division; [3] some of his explanations of other exceptional cases, although ingenious, will not now bear critical examination. One of the most difficult is that of the hive bee and those insects resembling it, in which all eggs have two polar divisions and when fertilized yield females, when parthenogenetic, males. Castle supposed that the female determinant is extruded with the second polar nucleus, leaving the egg male bearing, and accepted the observations

[1] "The Heredity of Sex," Bull. Mus. Comp. Zoo. Harvard, vol. 40, p. 189.

[2] Science, May 17, 1907, p. 779.

[3] E. g. Stevens, Journ. Exp. Zoo., vol. 2, 1905, p. 313. But Morgan (Proc. Soc. Exp. Biol. and Med., vol. 5, 1908, p. 56) finds in *Phylloxera* that the females have six chromosomes, the males five. And Stevens (Journ. Exp. Zoo., vol. 6, 1909, p. 115) suggests that in *Aphis* also one complete chromosome is extruded in the maturation of male parthenogenetic eggs, but not in female eggs. [This has since been confirmed. Biol. Bulletin, vol. 18, p. 72, 1910.]

of Petrunkewitsch,[1] who maintains that the testis of the drone is derived from the fused polar nuclei of the unfertilized egg. Since the second polar nucleus by hypothesis contains the female determinant, the spermatozoa may be female bearing and cause the fertilized egg to be female. But there is considerable doubt as to the accuracy of the observation, and in any case it can not be applied to some others; e. g., Silvestri (see above) finds that in *Litomastix* the polar nuclei are used up in forming the protecting membrane of the embryos, and yet the sex phenomena are just as in the bee. An alternative speculation may be offered. It is possible that while the female determinant is extruded in the virgin egg with the second polar nucleus, the presence of a spermatozoon in the egg may cause the male determinant to be eliminated, leaving the egg nucleus female bearing.[2] This would fall into line with the explanation suggested above of gynandromorphic bees—that in them the sperm has conjugated with the second polar nucleus.

It now remains to describe work on the determination of sex which has led to similar conclusions to those suggested above, but arrived at from a different starting point. Castle suggested that as sex is inherited as a Mendelian unit, it might at times be "coupled" in the gamete with some other body character. It has been found that something of this kind actually does take place in the case of certain varieties which are inherited differently by the male and female. As an illustration of this we will take some experiments made by the writer, accounts of which have already been published,[3] since the results in that case happen to be simpler than in some other instances which have been worked out.

In the common currant moth (*Abraxas grossulariata*) there is a rare and very distinct variety ("lacticolor") found in the wild state almost exclusively in the female. Crossing experiments were made between this variety and the type form; the results were as follows:

(1) Lacticolor ♀ × type ♂ gave type ♂, type ♀.
(2) Heterozygous (crossed) type ♀ × heterozygous type male gave type ♂, type ♀, lacticolor ♀.
(3) Lacticolor ♀ × heterozygous type ♂ gave { type ♂, lacticolor ♂. / type ♀, lacticolor ♀.
(4) Heterozygous type ♀ × lacticolor ♂ gave type ♂, lacticolor ♀.
(5) Lacticolor ♀ × lacticolor ♂ gave lacticolor ♂ and ♀.
(6) Wild type ♀ × lacticolor ♂ gave type ♂, lacticolor ♀.

These results at first may seem hopelessly confusing, but there are several points of interest about them. Firstly, the lacticolor character behaves as a Menedlian recessive, disappearing in the first cross

[1] Zool. Jahrb., vol. 14, 1901, and vol. 17, 1903.
[2] I find that this suggestion has also been made by Prof. T. H. Morgan.
[3] Doncaster and Raynor, Proc. Zoo. Soc. 1906, vol. 1, p. 125; and Doncaster, Reports to Roy. Soc. Evolution Committee, vol. 4, 1908, p. 53.

(No. 1) and reappearing after mating (2). Secondly, starting with a lacticolor female, it is possible to get males of that variety only in one way, viz, by pairing such a female with a heterozygous male, i. e., a male which is typical in appearance, but being of lacticolor parentage bears the recessive lacticolor character. Lacticolor males are also produced from mating lacticolor males and females together (No. 5); but from any other form of union all the lacticolor individuals which emerge are females. A third point of great importance is that converse crosses do not give similar results, the most unexpected case of this appearing in matings of types No. 1 and No. 6. In the first, a lacticolor female paired with a wild (pure) type male gives all the offspring of both sexes perfectly typical, a quite normal Mendelian result, since lacticolor is recessive to the type. But if an apparently pure, wild female is mated with a lacticolor male, the male offspring are typical, but the female are all lacticolor—exactly the same result in fact as when a first-cross female is used instead of a wild one.

In explaining these phenomena in the first paper this last result was not known; and it was suggested (in accordance with Castle's hypothesis) that the germ cells bore one or the other sex, that fertilization was selective, so that all individuals were heterozygous in respect of sex and that in the eggs the lacticolor character was coupled with the female sex determinant. Later Bateson and Punnett[1] offered a modified hypothesis, which is perhaps more in accord with the facts as known at present. They suggest (1) that the sex determinants behave as Mendelian units, femaleness being uniformly dominant over maleness; (2) that female individuals are heterozygous in respect of sex, being of the constitution ♀ ♂ and producing male-bearing and female-bearing eggs in equal numbers; males are homozygous in sex, of the constitution ♂ ♂, so that they produce only male-bearing spermatozoa; (3) that there is repulsion in oogenesis between the dominant determinant for femaleness and the dominant grossulariata (type) determinant, in consequence of which all male-bearing eggs bear the type, all female-bearing eggs the lacticolor character.

This suggestion completely accounts for the facts and has since been greatly supported by the discovery that all females with the type (grossulariata) character are heterozygous and produce lacticolor offspring when paired with a lacticolor male. This fact compels us to assume that the lacticolor determinant is present in all females of the species and is only prevented from appearing because typical males bear normally only the type (grossulariata) character, which dominates over lacticolor. If, then, the males are homozygous

[1] Science, vol. 27, 1908, p. 785.

and the females heterozygous in respect of a character so intimately related with sex, it strongly supports the idea that the same may be the case with the sex determinants themselves.

If this instance stood alone it might seem rash to found on it such a far-reaching theory of the nature of sex. But exactly similar cases have been found elsewhere. Miss Durham[1] has described almost identical phenomena in the case of canaries of the Cinnamon variety, which have pink eyes. A pink-eyed hen paired with a black-eyed cock gives offspring which are all black-eyed; but a black-eyed hen by a pink-eyed cock gives males which are all black-eyed, and pink-eyed females, together with sometimes a small proportion of black-eyed females. This occurrence of exceptions suggests some disturbing factor not present in the moths. Bateson,[2] and Pearl and Surface,[3] have discovered similar cases in fowls, and Correns from experiments on plants (*Bryonia*) has come to a similar conclusion,[4] except that he regards the male as heterozygous and the female homozygous.

Confirmatory evidence may be drawn from other observations. One of these is the effects of castration. In vertebrates castration of the male may prevent the appearance of the male secondary sexual characters but does not cause the appearance of characters proper to the female. Removal or atrophy of the ovary, however, may bring about the development of characters normal in the male. In the Crustacea the opposite result is found.[5] A female whose ovaries are destroyed by a parasite has its secondary sexual characters reduced; a male assumes more or less completely the characters of the female. And if the parasite dies and the host recovers, the ovary of the female may again become functional; but in the male under such circumstances eggs may be produced in the testis. Geoffrey Smith concludes from these observations and from others on the Cirripedes that the female is homozygous in sex and the male heterozygous. There seems no a priori reason why this should not be true in the case of the Crustacea and flowering plants, while the converse is the case in moths and vertebrates.[6]

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[1] Reports to Roy. Soc. Evolution Committee, vol. 4, 1908, p. 57.

[2] See note in Science, vol. 27, 1908, p. 785, referred to above. For full account of this case, and discussion of the whole subject, see Bateson, Mendel's Principles of Heredity (Camb. Univ. Press, 1909), Chap. X.

[3] Pearl and Surface, Ann. Rept. Maine Agric. Exper. Station, 1910, pp. 84–116.

[4] Bestimmung und Vererbung des Geschlechtes (Borntraeger), 1907.

[5] G. Smith, Naples Monograph, Rhizocephala, 1906. [See also Smith, 'Studies in the experimental analysis of sex.' I–V, Quart. Journ. Micr. Sci., 1910–11.]

[6] [This was written before the publication of Morgan's important papers on Sex-limited inheritance in *Drosophila* (Science, vol. 32, 1910, p. 120, and American Naturalist, vol. 45, p. 65, 1911). In this fly the inheritance of several characters shows phenomena the exact converse of those found in *Abraxas*, indicating that the male is heterozygous for the sex determiner, and transmits the characters concerned only to his female offspring. This suggests either that in some cases, e. g., *Abraxas* and fowls, the female is heterozygous and the male homozygous, in others, e. g., *Drosophila*, the male is heterozygous and the female homozygous for sex determiners, or that both sexes are heterozygous with selective fertilization. For fuller discussion of this more recent work the reader is referred to the papers on the subject by Morgan, Wilson, Miss Stevens, the writer, etc.]

One of the points of difficulty about the theory that one sex is homozygous and the other heterozygous in respect of the sex determinants is that it appears inconsistent with Wilson's theory based on the study of "idiochromosomes." But phenomena such as he describes have hardly been observed outside most orders of insects and possibly Arachnids, and are probably not of universal occurrence. And if all individuals of one sex are heterozygous, those of the other homozygous in sex, it may be imagined that in the homozygous sex two sex determinants would not be necessary; one of them might become vestigial, as Wilson describes, if at the same time spermatozoa bearing such a vestigial determinant can only conjugate with eggs of one kind. But it must be admitted that any suggestion of selective fertilization interferes with the extreme simplicity of the theory outlined above.[1]

The hypothesis here described not only explains the cases which led up to it and such facts as the effects of castration, but also accounts for the phenomena of sexual dimorphism and the inheritance of some structures by one sex only. But at present the more complex cases of sexual polymorphism, such, for example, as are known in the African butterflies of the genus *Papilio*, still remain obscure, although it is probable that when we have more extensive records of breeding experiments, these also will be found to fall into line. And it should be explained that some forms of sex-limited inheritance are of quite a different nature—e. g., color blindness and the disease hæmophilia in man. In these diseases the abnormal condition is dominant in one sex (male) and recessive in the other and may appear in the female if both parents are tainted. Possibly a combination of some condition of this kind with sex relations, such as we find in *A. grossulariata* and the Cinnamon Canary, may ultimately be found to account for the complex sexual polymorphism found in the African Papilios.

We have now sketched the principal lines of evidence which have been collected in recent years, pointing to the conclusion that the sex determinant is present in the germ cell and is probably comparable in nature with a Mendelian unit. In a paper of this kind it is clearly out of place to attempt even to mention a tithe of the numerous hypothesis concerning sex which have been advanced even in

[1] Wilson has recently (Science, vol. 29, Jan., 1909, p. 53) put forward a fresh suggestion, viz, that the idiochromosomes do not bear the determinants for maleness or femaleness as such, but that one idiochromosome in the fertilized egg causes it to develop into a male, two into a female, so that the difference is rather quantitative than qualitative. Castle (Science, vol. 29, Mar., 1909, p. 395) has taken up this idea with the further suggestion that while some species are as Wilson suggests, in others the presence of one idiochromosome determines femaleness and absence of any idiochromosome at all brings about maleness. If this last condition should be found to exist in *Abraxas grossulariata*, it would then fall into agreement. In this connection it is of interest that cases such as Wilson describes have been observed in most of the chief orders of insects but not in the Lepidoptera.

very modern times. Many of them do not concern the point at issue, dealing as they do with possible factors which may influence the sex of a given individual; for we have seen that, whatever the true nature of sex may be, it is conceivable that the proportion of germ cells bearing one or the other sex which come to maturity may possibly be influenced by external conditions. To do justice to what has been written on such subjects would require a book of considerable size and in the present paper is impossible. The object of this account will have been fulfilled if it indicates the direction in which recent work is leading and if it makes it clear that the probabilities are overwhelmingly in favor of the idea that the determination of sex is not consequent on the accidental preponderance of one or other of two nicely balanced tendencies, but is due to fixed and unalterable characters inherent in the germ cells.

THE SIGNIFICANCE OF THE PULSE RATE IN VERTEBRATE ANIMALS.[1]

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We should expect the frequency with which a heart beats to be determined by its own properties—by its size, the minute structure of its muscle fibers, the inorganic salts in and outside the fibers, temperature, its relation to the nervous system, etc.; and it probably is immediately determined by such things as these. At present, however, we do not know the properties in which the hearts of allied animals, beating with very different frequencies, differ from one another, and we are not therefore in a position to point to the immediate determining factors. All we know is that the properties, whatever they are, which determine frequency have come to be such as to enable the heart to serve the purposes of the animal to which it belongs. It is proposed in this paper to attempt to ascertain whether we can find out some of the different ways in which the heart serves these purposes, and whether or to what extent alteration in frequency of beat is one. To do this we must first know something about the different purposes for which the heart is required in different animals.

In the first place, the amount of driving work the heart has to do varies a good deal in the different craniate vertebrates and both with the structure and the habits of the animal. In fish, e. g., it has only to pump the blood as far as the gills, and it has not much to do even in effecting this, as the passive dilatation of the gill capillaries with each inspiratory movement of the buccal cavity helps the blood to get there (1).[2] In accordance with this small amount of work, we find the heart to be of relatively small size in fish. Its weight in the common round fish is on the average only 0.09 per cent of the body weight; in the notably inert flatfish it is even less, only about 0.04

[1] From a lecture delivered to the Oxford University Junior Scientific Club in November, 1909. Reprinted by permission, with author's additions and corrections, from Science Progress, London, No. 17, July, 1910, pp. 60–81.

[2] These numbers refer to a list of authorities given at the end of the paper.

per cent of the body weight (2). In birds, on the other hand, the heart has a very large amount of work to do, especially in the birds of passage and those that sing. Accordingly they have relatively very large hearts—1 to 2 per cent of the body weight, as a rule (3), and sometimes, as in the thrush and golden oriole, as much as about 2.6 per cent. The size of the heart has thus no fixed relation to the size of the animal to which it belongs. The heart of a pigeon, e. g., weighs 25 times as much as that of a plaice of the same weight, and is about equal to that of a salmon 15 times as heavy as the pigeon. A thrush and a guinea pig of six or seven times its weight have hearts of about equal size.

Frequency of beat, if it be in any way determined by the absolute size of the heart, is certainly no direct function of it. It is true that we have reason to believe, as we shall presently see, that the pulse rate in the thrush is not very different from what it is known to be in the guinea pig, but it would also not be very different from what it is in the rabbit, which has a heart of over twice the size. We know very little about what the frequency is in different fish and for those in which it has been accurately determined (*Telestes* and *Barbus*) the size of the heart has not been ascertained, though, assuming the relative size to be the same as in the other round fish, we should expect it to be no larger than that of a canary. In both these fish the frequency varies, in different individuals, between 40 and 70 per minute at room temperature, and no elevation of temperature raises it to beyond 125 per minute (1), whereas the heart of a canary may (7) beat with a frequency of 1,000 per minute.

If the animal made some demand on the heart for a definite volume of blood in unit time, frequency of beat might be expected to bear some relation to the relative size of the heart. Only it would be difficult to discover such a relation unless in a group of animals having the same circulatory arrangements some required a quicker and others a slower circulation for some assignable reason.

For the lower groups of craniate vertebrates (fish, dipnoi, amphibians, and reptiles) we know very little as to the special demands made upon the heart. It has certainly more work to do in amphibians and reptiles than in fish, having to drive the blood all round the body without the help of the respiratory movements which seem to play so large a part in maintaining the circulation in fish (1). The relative heart size is accordingly greater in amphibians and reptiles. In the frog (*R. temporaria*) and in a crocodile the heart was found to be about 0.4 per cent of the body weight and to be nearly 0.8 per cent in the common snake (7). But we do not as yet know what the tissues take most from the blood in these lower vertebrates; we only know for a certain number of species of fish and amphibians and for the crocodile (6) that they take very little oxygen and that the rate

at which this at least is supplied is not likely to cause difficulty. Neither has anything yet been ascertained about differences in pulse rate in different genera of amphibians nor in those of any of the different classes of reptiles; so that we have not the material for deciding whether the frequency with which the heart beats has become one of the factors used in natural selection. In the few species of amphibians and reptiles (6) for which—sporadically—the frequency is known, it seems to be not very different from what it is in fish—i. e., varying (and varying in individuals of the same species) between about 20 and 80 per minute at ordinary room temperature.

In birds and mammals the case is different. We not only know that the tissues take a great deal of oxygen from the blood, but that those of small animals take much more than those of large ones; and we can assign a reason. Birds and mammals are able to maintain a nearly constant temperature whatever that of their surroundings may be. They are *homœothermic* or (the temperature they maintain being usually higher than that of the environment) "warm-blooded" animals; they have in consequence to produce more heat than those animals which maintain no constant temperature—the *poikolothermic* or "cold-blooded" animals—and to try to prevent loss of heat. To produce heat the muscles—the chief heat-forming organs of the body—require oxygen, and they take it from the blood according to their need, the need being greatest in those species or individuals in which the loss of heat is greatest. The maximum loss is of course in those animals in which the surface exposed to the environment is largest in proportion to the mass of the animal—i. e., the smaller the animal the more heat must it give off, other things being equal, to a colder environment, and to maintain a constant body temperature the more heat must it produce and the more oxygen must its muscles consume. The heart, therefore, being asked to replenish the supply, must, if it respond, give out the larger relative volume of oxygen-containing blood in unit time the smaller the animal, and it might do so either by expelling a larger amount with each beat or by increasing the frequency of the beat.

But by regulating the volume of blood supplied to the muscles in unit time, the heart can only regulate the rate of supply of oxygen if the oxygen is present in a constant percentage. This is the case in birds and mammals in which the blood in the systemic circulation leaves the left ventricle of the heart with its hæmoglobin saturated with oxygen. It is not the case in the lower vertebrates, not even in crocodiles; for although they, like birds and mammals, have the oxygenated blood completely separated from the rest in the heart, it becomes mixed with other blood in the dorsal aorta, and may become so even in the conus. In other reptiles facilities for the admixture of the blood coming from the lungs with blood coming from other parts

of the body are greater, since it may happen even in the ventricle. In the dipnoi and amphibians, moreover, other organs besides the lungs have respiratory functions, and the blood from the rest of the organs in the body may mix with oxygenated blood elsewhere than in the ventricle and the arterial system. Where there is only one auricle, as in the dipnoi, and blood of all qualities enters the ventricle simultaneously, the percentage of oxygen in all the blood leaving the ventricle must be variable. Where there are two auricles, the one of which receives only oxygenated blood, as in amphibians and reptiles, this need not be the case, since the blood from the lungs, by entering and leaving the ventricle after the rest, may remain very nearly saturated. But such blood is by special arrangement supplied to the head only, and the blood to the limbs and other muscles is unsaturated. In all these classes of lower vertebrates, therefore, the heart itself could not regulate the rate of oxygen supply to meet different demands by altering either the volume given out per beat or the frequency of the beat.

In fish, on the other hand, there is the possibility of regulating it, either by altering the frequency of the respiratory movements or by altering the volume of blood expelled in each heart beat, since all the

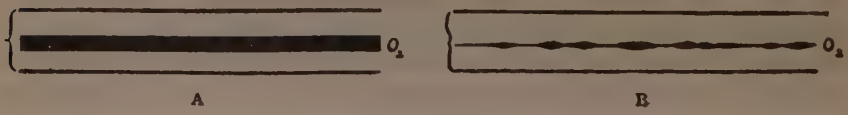


FIG. 1.—Diagrams to show the sort of relation of the oxygen to the blood-volume in the systemic circulation.
A, warm-blooded vertebrate. B, reptile and amphibian.

blood which supplies the body has to pass first through the respiratory organs, and so would contain a constant percentage of oxygen, even if its hæmoglobin did not become fully saturated.

In fish, amphibians, and snakes, the attempt seems occasionally to be made to maintain a temperature above that of the environment (16A), but in how far it approaches to being constant we only know for two specimens of the Indian python (13A). It would be interesting to find out whether in a species of *Thynnus*, the bonito, which may have an internal temperature as much above that of the environment as the python, it is more nearly constant, and how far the demand for oxygen in the one and in the other varies both with the external temperature and with the size of the individual; moreover, if it so varies, in what way the supply is regulated to meet the different demands.

The difference obtaining between the warm-blooded vertebrates on the one hand, and all the cold-blooded except fish, on the other, with regard to the relation of the oxygen to the volume of the blood in the systemic circulation, is illustrated in figure 1. Regulating the volume rate would regulate the oxygen supply only with arrangement A.

With any other arrangement, such as that in B, the absolute amount of oxygen supplied in unit time could be increased by increasing the frequency of the beat, but it could not in that way be regulated at all accurately to suit special demands.[1]

What is true of the cold-blooded vertebrates is true of the embryo of the warm-blooded animal in respect of want of constant percentage of oxygen in the blood supply to the body as in so many other respects. Although the blood leaving the left ventricle is blood brought straight from the respiratory organ of the embryo, the allantois, this serves only to supply the head, the great aorta through which it flows being joined, after having given off the vessels to the head, by the ductus Botalli bringing blood (through what is afterwards the pulmonary artery) from the right ventricle, which has received it from all the organs and reserved all but that from the respiratory organs. Thus the percentage of oxygen, which may have been constant in the blood leaving the left ventricle, is no longer so by the time it reaches the body of the animal, and this must continue to be the case so long as the ductus Botalli remains open, which it does until the time of hatching or birth. When it closes, the blood from the right ventricle, which would otherwise have gone along it, can only go to the lungs, and the channels from the lungs to the left auricle, the pulmonary veins, become functional with the lungs themselves, so that now blood saturated with oxygen enters the left auricle from the respiratory organ of the adult, and (the septum between the two auricles being now complete) passes unaltered into the left ventricle, whence it is driven to supply not only the head, but now also the body. It would be interesting to know whether in the young guinea pig and chick, which are able to regulate their temperature as soon as they come into the world, the ductus Botalli closes earlier than it does, e. g., in young mice, rats, and pigeons, which can only regulate their temperature very imperfectly when born or hatched, and take a week or more to develop this power. It would help us to find out whether, or to what extent, the want of power to regulate temperature depends upon the fact that any attempt of the heart to adapt itself to meet special

[1] Since this paper went to press, Krogh has published a series of articles in the Skand. Arch. f. Physiol. (1910) in which, amongst other things, it is shown that a method of regulating the oxygen supply to the body does exist in reptiles and amphibians. This consists in adjusting the relative volumes of blood in the pulmonary and systemic arches by alteration of resistance in the pulmonary arteries, this being effected by variations in the tonus of their vaso-constrictor nerves. Thus, while the blood per beat driven into the systemic circulation becomes less in volume the more oxygen the tissues consume, its oxygen-tension becomes not only relatively, but absolutely, greater in consequence of the increase in the volume going per beat through the lungs, which naturally involves a greater absolute absorption of oxygen. Although a convenient way of meeting differences of oxygen requirement in the individual, it is not one that would lend itself to meeting permanent differences of oxygen requirement, did these exist, in the different species of reptiles and amphibians, in the way that alteration of volume rate lends itself in birds and mammals.

demands made upon it for oxygen, potentially or actually, could meet with only imperfect success.

Let us now see in how far the hearts of birds and mammals, having the power to regulate the oxygen supply by regulating the volume of blood expelled in unit time, succeed in doing so when it is asked of them. As a measure of the rate at which oxygen is consumed in the different animals we may take either the oxygen intake or the carbon-dioxide output of a unit of weight in unit time, as the two things run roughly parallel. In the two following tables the carbon-dioxide output is given because it happens to be known for a larger number of species than the oxygen intake. The numbers are for the most part taken from the table in Pembrey's article on "Chemistry of Respiration" in Schäfer's Textbook of Physiology and represent the average in round numbers when several results are there given by different observers. Those for birds which are not to be found there are determinations kindly made for me by Mr. C. G. Douglas, fellow of St. John's College, Oxford.[1] The pulse rates of all the birds and of the smaller mammals have been determined by myself in a manner to be described immediately; those of the larger mammals have been taken on textbook authority when none other was available. As a measure of the volume of blood expelled per beat the weight of the heart in percentage of the body weight has been taken. This has been determined for a large number of birds by Parrot (3), but unfortunately not for many of which the pulse rates are known. For most of these, as well as for the mouse, I have determined it myself. For most of the other mammals mentioned it has been determined by Bergmann (8), but the results of his observations are referred to, together with some more determinations of his own and those of a few other people for other mammals, by Joseph (9). Unfortunately the number of individuals from which the "average," either of pulse rate or of relative heart weight, is taken was usually small and sometimes (in all the cases marked with an asterisk) the data were only ascertained from a single individual of a species; as we know that in other species there is a good deal of individual variation, the numbers given in these columns may not hereafter be found to be the correct averages. They probably are so, however, in the case of man and rabbit, in which they have already been ascertained from large numbers of individuals. It is, of course, highly desirable that the correct average should be known for every case, but it is difficult to get people to make large collections of facts, and it is debatable in how far their doing so is a thing to be encouraged, so long as the interest attaching to them is not in evidence. The fol-

[1] For each bird he determined also the oxygen intake; since this datum for the canary and for the tame duck has not yet been put on record, this occasion may be used for stating that it was found to be 10.99 and 1.66 grams per kilo per hour, respectively, for the two birds. The canary was remarkably quiet all the time it was under observation.

lowing tables, if they serve no other purpose, at least indicate the sort of value which would attach to a large collection of these particular facts.

TABLE I.—*Birds.*

Bird.	Average weight (in grams).	Average carbon dioxide per kilo per hour (in grams).	Average heart weight in percentage of body weight.	Average frequency of beat per minute when at rest.
Goldfinch	*16	12.6	(?)	*920(5)
Canary	20	*11.7	*1.04(3)	*1,000(7)
Sparrow	24	12.2	1.36(5)	800(5)
Greenfinch	26	11.7	(?)	740(5)
Kingfisher (young)	*42	(?)	(?)	*440(7)
Thrush	*75	(?)	*2.56(3)	(?)
Pigeon	300	3.4	1.5(5)	185(5)
Parrot (*Psittacus crithacus*)	*430	(?)	(?)	*320(7)
Hen	1,500	1.5	.42(5)	330(5)
Duck (wild)	*1,134	(?)	*1.06(3)	(?)
Duck (tame)	*2,060	*1.62	.63(2)	*240(7)
Goose	4,400	1.07	*.8(3)	(?)

The table for birds shows us at a glance that, roughly, the smaller the bird, and therefore the greater the surface relatively to the mass, the larger is the amount of oxygen consumed, or, rather, of carbon-dioxide given off, by a unit of weight in unit time. If the rate of supply of oxygen to the tissues is greatest, as it ought to be, in those in which the oxidation processes take place most rapidly, we should expect the pulse rates to vary directly with what we take as a measure of these processes so long as the relative volume of blood expelled with each beat is the same. Since the relative heart size varies, we should expect to find a reciprocal relation between pulse rate and relative heart size dependent upon the rate at which oxidation processes occur. Where we have these data, or a measure of them, the table shows us that this is the case. Thus, comparing the pigeon and the sparrow, and knowing the pulse rate of the pigeon, we should expect that of the sparrow to be $\frac{185 \times 12.2}{3.4} = 693$ in consideration of the different metabolisms, but to be $\frac{693 \times 1.5}{1.36} = 770$ per minute in consideration also of the different relative weights of the hearts; and this is what it is in some sparrows, though it is lower than what was found to be the average for four sparrows. Again, the hen, which compared with the sparrow, would be expected to have a pulse rate of $\frac{800 \times 1.5}{12.2} = 98.4$ per minute in virtue of its size and its metabolism alone, would be expected to have

one of $\frac{98.4 \times 1.36}{0.42} = 319$, considering also the small size of its heart. If we were to take the carbon-dioxide output of the thrush as being, as from the size of the bird it is likely to be, about 10 grams per kilo per hour we should have expected its pulse rate by comparison with that of the sparrow to have been about 666 per minute were it not for the large size of its heart, which makes us expect instead one of only 225 per minute. From what is known of the metabolism of the goose, we should expect its pulse rate to be about 144 per minute when it is in good condition; we should expect that of the wild duck to be not much more than half that of the tame, allowing for its carbon-dioxide output per kilo per hour being, on account of its smaller size, somewhat less than what Mr. Douglas found it to be in the tame duck of which the pulse rate was recorded. Small hearts and correspondingly quick pulses seem, therefore, to be more characteristic of tame birds than of wild, a subject to which we shall have to return.

TABLE II.—*Mammals.*

Weight in grams.	Mammal.	Average carbon-dioxide per kilo per hour (in grams).	Average heart weight in percentage of body weight.	Frequency of beat per minute.	
				Observed average when at rest.	Average to be expected by comparison with man.
25	Mouse	8.4	0.79(4) (2)	700(4)	732
300—500	Guinea pig	1.8	.40(9)	300(7)	309
2,000—6,000	Small dog	1.5	.9(9)	(?)	115
	Cat	1.3	.45(9)	160(7) (12)	198
	Rabbit	1.2	.27(9)	205(11)	306
	Hare	(?)	.75(8)	64(12)	(?)
6,000—10,000	Medium dog	1.37	.75(9)	120(7)	128
10,000—50,000	Large dog	1.	(?)	85(7)	(?)
20,000—100,000	Deer	(?)	1.15(8)	(?)	*45?*
	Sheep	.7	.60(8)	75	80
	Pig	(?)	.45(8)	75	*100?*
	Man	.6	.59(8)	70=	70
400,000—600,000	Ox	.45	.39(8)	48	78
	Horse	.3	.63(8)	37	34
	Race horse	(?)	1.12(13)	(?)	(?)

In the table for mammals a column has been added giving the pulse rate, which, taking both carbon-dioxide output and relative heart weight into consideration, we should expect the animal to have compared with man. Man has been chosen as the standard because so many more observations have been made on him that the averages are more likely to be correct than those for the others, with the exception perhaps of the rabbit. Of course, somewhat different

frequencies would be to be expected had we chosen for comparison some other animal. If, e. g., we had taken the relation of the mouse to the cat or rabbit we should have expected its pulse rate to be only about 590 or 490, respectively, per minute, which is lower than the average found for six mice.

	Carbon-dioxide output.		Pulse rate.	Relative heart weight.		Pulse rate.
$\frac{\text{mouse}}{\text{man}}$	$\frac{8.4}{0.6}$	=	$\frac{980}{70}$,	$\frac{0.59}{0.79}$	=	$\frac{732}{980}$
$\frac{\text{mouse}}{\text{rabbit}}$	$\frac{8.4}{1.2}$	=	$\frac{1435}{205}$,	$\frac{0.27}{0.79}$	=	$\frac{490}{1435}$

Considering that the rate of formation of carbon-dioxide, the relative heart size and the frequency of beat, have in the case of nearly all the species been determined by independent observers, it is really rather remarkable how closely the observed and expected frequencies agree. Only in the rabbit and ox[1] is the observed frequency considerably (over 30 per cent) lower than was to be expected from that of man. It is probably also about 25 per cent lower in the pig, though we have not yet the data for knowing what to expect for the pig. A higher hæmoglobin percentage in the blood would compensate for what seems to be otherwise too slow a blood supply to enable the oxygen loss to be made good, but although we know this percentage to be higher in the ox than in man, it is in the rabbit a good deal lower than in man. Since in the rabbit at any rate the averages are likely to be correct, we have probably still to seek for some other factor which enables the supply of oxygen to meet the demand. But it must be remembered that the relative heart weights may not run strictly parallel with the volumes of blood expelled at each systole in the different species. Unfortunately we do not know and it would be difficult during life to ascertain what that volume is for any heart; we have had therefore to take the only available data which were at all likely to be a measure of it.

None of the mammals referred to have pulse rates appreciably higher than those to be expected by comparison with man. All birds, however, so far as we know, have higher frequencies than might be expected when compared with mammals, thus, taking man again as the standard, that for the sparrow would be only 618 instead of 800 per minute.

	Carbon-dioxide output.		Pulse rate.	Relative heart weight.		Pulse rate.
$\frac{\text{sparrow}}{\text{man}}$	$\frac{12.2}{0.6}$	=	$\frac{1423}{70}$,	$\frac{0.59}{1.36}$	=	$\frac{618}{1423}$

[1] If the ox had the same relative heart weight as the bull (0.53 per cent), the pulse rate to be expected by comparison with man would be almost precisely what it actually is in the ox.

The hæmoglobin percentage does not appear to have been determined in the blood of birds, but in view of the greater size of the red blood corpuscles of birds as compared with those of mammals we might expect it to be lower. On the other hand, the fact that the consumption of oxygen and both relative heart weight and pulse frequency are higher in a bird than in a mammal of the same size (e. g., in the sparrow than in the mouse, in the pigeon than in the guinea pig) may have some bearing on the fact that birds maintain a higher constant temperature than mammals.

In this connection it is interesting to note that in the lowest mammals, the monotremes, and also in the marsupials, in which a lower body temperature is maintained, the heat produced, as measured by the carbon-dioxide output per kilo per hour, is much less than in so-called placental mammals of the same size (10). We know nothing at present about relative heart size or pulse rate in these animals. But since the monotremes regulate their temperature by the production of more heat when required (i. e., in cold surroundings) instead of by always producing a large amount and getting rid of the excess when necessary as the larger at any rate of the higher mammals do, we should expect the pulse rate in them to vary a good deal, and inversely, with the external temperature. The marsupials, utilizing also variations in loss of heat, although to a less extent than placental mammals of the same size, seem to regulate their body temperature extremely well. Of the two monotremes still living, *Ornithorhyncus* succeeds in doing so quite as well as some of the placental mammals; and *Echidna*, although it fails, makes the attempt for the greater part of the year, the oxygen consumption in the individual, at any given external temperature, seeming to some extent to vary inversely with the size according to the determinations made by Dr. Martin of the carbon-dioxide output per unit, weight, and time in three individuals (10). Those placental mammals which do not regulate their temperature the whole year round do not succeed much better than *Echidna* when they make the attempt, especially on first awaking from hibernation. In some of them the temperature seems to remain lower than in other placental mammals. The rectal temperature of a bat, for instance, may be only 30° C. when it is wide awake and active (16). The low temperature in such cases seems again to be due to the production of heat being small in comparison with other mammals of the same size. Thus in an active bat weighing about 20 grams, the carbon-dioxide output per kilo per hour was found to be only about 4.5 grams, and therefore considerably less than in a mouse. If we may take this as a measure of the demand for oxygen in an active bat, the heart need not beat with a frequency of more than 250 per minute to supply the demand, seeing that the heart of the bat, as we happen to know from two independent

sources (3) and (16), weighs as much as 1.2 per cent of the body weight, and is therefore relatively larger than that of the mouse. A very small dormouse on the other hand, in which the carbon-dioxide output may be as much as 20.4 grams per kilo per hour when awake (16), we should expect to have a pulse rate of over 1,000 per minute, even if it has as large a heart (relatively) as the bat.[1] It may have a pulse rate as slow as 16 or 14 per minute when hibernating (16A).

Before going further a few words should be said about the method of ascertaining the frequency of the beat in small warm-blooded animals. It would be difficult to count a frequency of over 300 a minute, or to record any mechanical movements of the heart when they are so rapid, in the living intact animal. We can, however, make use of the fact, the meaning of which is not yet sufficiently understood (5) and (6), that the electrical changes accompanying all muscular activity, and therefore that of the heart, produce in the case of hearts of mammals, birds, and certain if not all reptiles, two electric fields, the one of which pervades the anterior, the other the posterior part of the body. In order to record the rate at which the fields appear and disappear, we select some spot in each, e. g., the mouth and one of the hind legs, and with some good conductor of electricity (such as wool or thread soaked in salt water) connect each with a basin of salt water, these in their turn being connected with the terminals of an instrument sensitive enough to record such small differences of potential as come into existence between the two fields. Such an instrument is the capillary electrometer represented diagrammatically in figure 2, which shows a bird ready to have its pulse rate recorded. The instrument consists essentially of a fine glass tube drawn out so as to be only a few thousandths of a millimeter in diameter near the tip, and filled with mercury. The open end of the capillery tip dips into dilute sulphuric acid which enters so far as the mercury permits, the tube being very slightly conical so as just to prevent the mercury running out however near it be to the tip. The properties of the instrument are such that if the mercury becomes (galvanometrically) positive to the acid it moves toward it, if negative it moves in the opposite direction. Since the one field always comes into existence before the other, even though it may be by no more than a thousandth of a second, there is always a quick movement of the mercury in one direction while the single field exists. There may be other movements, but these first quick

[1] *Note added in 1911.*—Observations subsequently made by the author showed that an ordinary sized dormouse has a pulse rate of 600 to 700 when awake and warm and a heart weight which is about 1.2 per cent of the body weight; also that the pulse rate of a bat when awake is very variable, being in the very small form *Nannugo pipistrellus* now about 200, now about 900 a minute, now something between, while in the larger form *Plecotus auritus*, a specimen weighing 9.4 grams, had a pulse rate varying from 600 to 900 a minute (see 6A, and Proc. Physiol. Soc., Mar. 18, 1911).

ones, each the precursor of a ventricular systole, are easiest to count when recorded. To record the movements the image of the tip of the tube is magnified some three hundred times, and the boundary

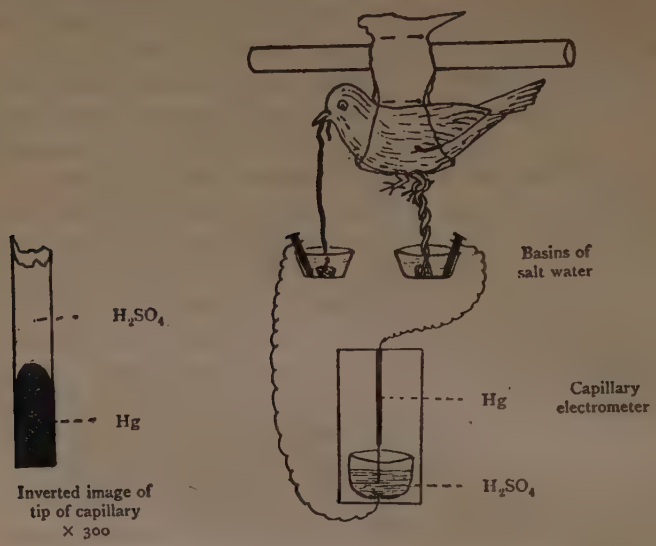


FIG. 2—Diagram of a bird having its pulse taken.

between mercury and acid is photographed on a moving plate on which is simultaneously projected the shadow of one end of a tunting fork vibrating at a known rate, so that the speed of the plate

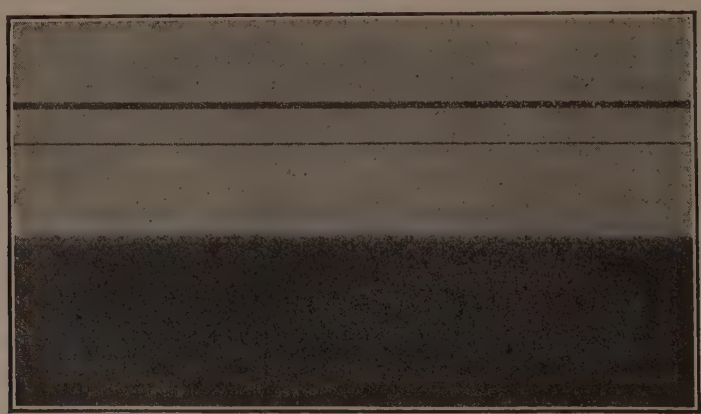


FIG. 3.—Electro-cardiogram of a goldfinch.

may be gauged. Figure 3 is two seconds' worth of a record taken with a goldfinch arranged in the way shown diagrammatically in figure 2. The tracing of a tuning fork vibrating one hundred times a second is seen above, and a thick and a thin horizontal line which

do not here concern us; the white below is the acid and the black the mercury. The record reads from right to left. It will be seen that the acid moved toward the mercury at regular intervals. These can be counted; in this particular photograph 30½ of them occur in the two seconds, indicating that the heart was beating at the rate of nine hundred and fifteen times per minute.

Until this method was introduced the frequencies of beat in small warm-blooded animals were not actually known. Their order had, however, already been inferred by Dr. Haldane from the known quick rate of consumption of oxygen. The method he introduced some 14 years ago of detecting the presence of carbon monoxide in mines, which has been the means of averting many disasters, depends essentially upon the fact that the more rapid the circulation is through the lungs, the more quickly is an animal affected by poisonous gases absorbed from the atmosphere and the more quickly does it recover in air free from such gases. Since carbon-monoxide, which is far more dangerous to life than any of the other gases which are formed when explosions or fires occur in mines, neither affects the sense organs nor produces pain, miners may remain unaware of its existence and so do nothing to avoid it, until they suddenly succumb. Had they only with them a mouse or a small bird in a cage, forming as much a part of their equipment as a safety lamp, they would have sufficient time to escape from a place which is dangerous, by leaving as soon as the animal showed symptoms, long before they themselves had absorbed a sufficient quantity to be incapacitated. If they are quick, the animal will live to aid them in finding a safe place of retreat. As it takes 14 to 15 times as long when at rest and 7 to 8 times as long when at work, for a man to be disabled as for a mouse, the miner, even if working, would have one or two hours for escape with such percentages of carbon-monoxide in the air as usually occur in mines (14).

The frequency of beat, as we have seen, has not become adapted by itself to regulate the supply of oxygen to the demands of the different warm-blooded animals, but other factors also play their part. We have shown that of these the principal one is the volume of blood expelled per beat. We have now to inquire what significance is to be attached to the fact that now the one and now the other of the two main regulating factors plays the more important part.

Parrot's observations on the relative heart weights of over 50 different species of birds and those others of birds and mammals referred to in our tables show that the relatively large heart is found in the more active animals. This is so not only in warm-blooded animals, but also, as we have already noticed, in fish, flatfish having a relative heart weight less than half that of more active fish. It is probably also the case in amphibians and reptiles, although we have

not yet the determining data; for, however small the demand for oxygen, all animals when active must consume more than when at rest and those that are habitually active must have some means of obtaining more. Moreover, since a large heart works more economically than a small one, in that it spends less of its time in overcoming inertia, it would for that reason also be favored when much work has to be done. The range of variation in relative heart size is fairly large in all species in which it has been determined in several specimens, but more so in some species than in others. Thus in four specimens of the golden oriole it varied between 1.8 and 2.6 per cent, while in seven of the curlew sandpiper it varied only between 1.6 and 2.0 per cent. In man, according to the determinations made by Bergmann from 36 people in whom death was accidental, the variation may be from 0.43 to 0.75 per cent. Müller (2A) dealing not with the weight of the whole heart, but only with that of the musculature, in percentage of body weight, in a large number of individuals who had died of different diseases, shows by his tables that in about 800 people dying between the ages of 30 and 60, this varied from 0.26 to 0.89 per cent, and further that the percentage weights of this musculature did not vary symmetrically about a mean, but asymmetrically about a mode (i. e., the percentage weight of the greatest number), and in such fashion that the mode (0.49 to 0.50 per cent) was nearer to the relatively small hearts than to the large ones, suggesting that the heart in man is becoming relatively smaller. The suggestion that man's ancestors were larger hearted is perhaps supported by the fact that in infants the modal ratio is about 0.6 per cent and even in children from 4 weeks to 3 years of age it is further in the direction of the large heart than in the adult, being about 0.53 per cent. But we have to be careful in drawing such inferences from data which can not be determined in the living, since we do not know in how far the heart ratio affects the death rate, a point which Müller, who interprets his tables in a way very different from that which is here suggested, seems to neglect. However this may be, we have ample evidence that in man as in other mammals, in birds, and so far as we know also in the lower vertebrates, the material is there to be selected from should it for any reason become advantageous for a species to alter its heart ratio in the future as it has probably done in the past. With regard to the past, it seems probable that such variations were used as material for selection before they became correlated with frequency of beat and that it was with the size of the heart more or less already determined that this frequency, which is also known to be variable in individuals, began to be used when it began to be advantageous to be independent of external temperature, owing perhaps to a change from an equable to a variable climate. In the present state of our

knowledge it is difficult to point to any advantage which might accrue to any species of poikilothermic vertebrate from having a particular pulse rate, nor apparently is the variation in different species greater than that in individuals in this respect.

When frequency came to be correlated with relative heart size for the regulation of the rate of oxygen supply to the heat-forming tissues, the slow pulse would tell as an advantage as well as the large heart in animals having to make great sustained effort; for a slow pulse as compared with a quick one means longer diastoles more than longer systoles, the systole requiring to be very little longer to expel a much larger quantity of blood, since, in contracting, the walls (the surface) of the ventricles decrease with the square, the contents with the cube. The longer the diastole the more time has the heart to recuperate between the beats when the animal is at rest and the greater power has it in time of need of increasing the oxygen supply to the tissues by increasing the frequency of the beat. The pulse rate of the rabbit only goes up to an average of 324 per minute after a few minutes' chasing about or after section of the vagi (11), thus increasing the oxygen supply by one and a half times at the most; that of the hare goes up under similar circumstances to 264 per minute (12), so that if the same amount of blood were expelled in each systole as when the animal was at rest the oxygen supply might be increased as much as four and a half times. MacWilliam, drawing attention to the connection between slow pulse and staying power, remarks (12) with regard to these particular closely allied animals, that "the rabbit is able to run short distances with great rapidity, but not to traverse long distances without intermission—this being no doubt in relation to the fact of their having burrows to flee to; the hare, on the other hand, destitute of such means of protection, has to depend, in the open country, upon its endurance in swift locomotion." The relative size of the hare's heart, according to Bergmann's estimations, appears to be nearly three times that of the rabbit's; and of the pulse rates of the two animals at rest that of the rabbit is about three times that of the hare. That staying power rather than wildness itself has led to the larger heart being favored is shown by the fact that there is very little difference in the relative heart weights of the tame and the wild rabbit (9).

The relatively small heart of animals kept for food, such as the hen, the tame duck, the pig, the ox, and the cow (in which it is the same as in the ox) is, on the other hand, a consequence of the artificial fattening up of these animals, thus increasing their body weight, while their hearts, having little to do, do not keep pace, it being possible to supply the oxygen demanded by increasing the frequency of beat. The animals with the smallest hearts would be selected for the purpose in question by man just because of their

being the least active. By similar artificial (though also unconscious) selection in the other direction, the relatively large heart of the race horse would be accounted for, while in the case of the deer and the bat, which are the only other mammals, of those in which relative heart weight has already been determined, with so large a heart as the race horse, the same end has been achieved by natural selection.

That frequency of beat in a resting condition, as well as relative heart size, furnishes material (whether it is used or not) for natural (or artificial) selection to work on is a fact of common experience so far as man is concerned. I have found it to vary between 45 and 90 per minute in quite healthy people. The extent of the range seems to be very different in different species, thus in the mouse it varies between 520 and 810 per minute, in the rabbit between 123 and 306 per minute, while a veterinary surgeon informs me that in the ordinary horse its range of variation is between 34 and 40 only in health. Hering's observations on the pulse rates of 43 rabbits show that the modal resting frequency is lower than the average frequency, thus suggesting in the case of the rabbit what Müller's observations did in the case of man, that it has come from a slower pulsed and larger hearted race.

Can we go further than showing that variations in frequency exist to be selected from if need be, and indicate also the method by which the heart in birds and mammals has succeeded in adapting itself to the needs of the organism? We know that regulation of heat in every individual warm-blooded animal is brought about by the agency of the central nervous system. We know also that a warm-blooded animal never is cold, although it feels cold when brought into cold surroundings, while a so-called "cold-blooded" one which really does become cold under similar cicumstances does not feel cold, if we may judge from its behavior. We find that instead of making the attempt to produce more heat to counterbalance the loss, by eating or moving about, it refuses to do either of these things in the cold. It will not even choose the warmest place and so prevent as much loss of heat as possible. I kept a young crocodile for some months in a long trough so arranged that one end but not the other might be heated from outside. It was so heated every night when the weather was cold, but the crocodile was found indifferently in any part of the trough in the morning, until at last one night in a somewhat longer spell of cold weather it died at the very farthest extremity of the trough from the warmed part. It could have been in a surrounding temperature of 8° C. had it liked; it chose one that was hardly above freezing point and died there. A warm-blooded animal, feeling the cold, would have made every effort both to prevent loss of heat and to produce more heat, and even without effort it

would, with the aid of the central nervous system, that is to say reflexly, have done one or other or both things, in some species more the one, in some more the other.

Is it also by means of the central nervous system that the muscles, put into play either voluntarily or involuntarily to produce the extra amount of heat and taking up more oxygen from the blood, ask the heart to make good the loss? It is well known that muscular action is accompanied by acceleration of the heart, and that acceleration of the heart may be brought about by the intervention of nerves. But to answer the question we have to know a good deal more than this, and, in the first place, whether either reflexly by the excitation of the afferent nerves of the muscle or by the excitation of motor cells of the cortex such acceleration can be produced, also whether poikolothermic vertebrates differ from homœothermic ones in this respect. That it can be produced in one or other of these ways in one species of homœothermic vertebrate, namely man, is shown, I think conclusively, by the results obtained from experiments which, by the kindness of several Oxford undergraduates in serving as subjects for them, I have been able to make. Having recorded the frequency of the beat with the subject sitting quietly with one hand and one foot in basins of salt water connected with the terminals of the capillary electrometer, it was then again recorded when, instead of being at rest, he clenched the fist that was free, or made some other definite muscular action, on hearing a signal given automatically just as the plate began to pass behind the capillary electrometer and with the exact moment at which it was given recorded on the plate. The reaction time of the subject to the particular sound had been first ascertained with the same instrument, in a way which need not be here described, to enable us to tell the moment at which the muscular action began to be made, and to see in how long or how short a time after it the acceleration of the heart took place. We have of course to take our chance as to when in a cardiac cycle the signal is given, but by taking a sufficient number of records we are likely to meet with it in all phases of the cycle. The amount of the acceleration with such a slight action as clenching a fist is very different in different people, but if it is marked at all we have no difficulty in ascertaining that it occurs so promptly that if the muscle begins to contract only at the end of a systole, the immediately ensuing diastole of the same cardiac cycle is considerably shortened and that of the following cycles still more so. Thus in a man whose heart when at rest was beating very regularly 73 times a minute, the period of the cycle being therefore 0.82 second, the period became 0.67 second when the fist was clenched at the end of the systole, and the next ones were 0.57 or 0.56 second, the frequency being thus temporarily raised to over 100 per minute. That the stimulus should be anything

involving mechanical movements of the blood is hardly conceivable. The shortening of the cycle in cases of such slight action is due to shortening of the diastole only, and MacWilliam's researches (12) on cats have shown us that it is the vagus nerve which principally, if not solely, affects the duration of diastole, and that stimulation of the peripheral end of this nerve produces an immediate effect, whereas that of the accelerator nerve to the heart (the sympathetic) takes some few seconds to produce one. We can therefore not only say from the promptitude with which the heart accelerates when a voluntary action is made that it is due to nerve action, but also that it is the vagus nerve which conveys the impulse to the heart and therefore that the nerve which acts on the vagus center, whether the sensory nerve of a muscle or an axon from a cortex cell, acts in such a way as to suspend the tonic action of the center. Bowen, in a paper (15) discovered after these experiments had been made, has shown that even so small an action as gently tapping a key, the subject being at rest with his arm supported on a table, produces a prompt acceleration of the heart. His method of recording does not show so well as that described above how prompt it is, but he saw that it was enough to indicate that it could only be brought about by the mediation of the vagus.

Of course many other factors—chemical, mechanical, and thermal, as well as nervous—must play some part in producing the strong acceleration of the heart consequent on severe exercise, when the frequency may become in man 170 or 180 per minute, and when the duration of the systole as well as that of the diastole is shortened. To answer our question we require to know whether it is to them or to nervous factors only that the acceleration is due which occurs with *involuntary*, reflexly produced, muscular movements for the regulation of temperature such as shivering, evidence of which acceleration I have obtained from one or two medical undergraduates who kindly took their pulse rates several times under conditions which induced shivering for comparison with what it was before the shivering commenced. Since the shivering can not be made to begin at a precise moment, we can not ascertain in the same way as for voluntary movements whether the heart acceleration as well as the movement itself is brought about by the agency of the central nervous system; but there is a certain amount of likelihod that the two things should be effected in the first instance by the same agency. The fact that the arousing to activity of the central nervous system of a hibernating animal makes it not only begin to shiver (17) or become very active so as to produce heat, but at the same time (or even previously) quickens the heart beat very considerably (see 6A), also suggests it. It might perhaps be determined whether it were so or not by seeing whether in the first place the animal managed to hibernate

if the action of the vagus on the heart were prevented, e. g., by the administration of atropine; whether in such case the frequency of beat was reduced to the same extent, and if so, secondly, whether under a continuation of the treatment heart acceleration occurred, and occurred as promptly, on awakening from hibernation. If in spite of such procedure the animal when awake still succeeded in regulating its temperature, we should know that other agencies than the central nervous system were more intimately concerned in adapting the heart to meet the demands made upon it. We should then be in a better position than we are now to discuss whether the power which we have shown to be exercised by the heart in the different species of warm-blooded animals of complying with the demands made upon it, not on occasion only but for life, has been evolved under nervous control.

REFERENCES.

(1) Kolff, Arch. f. d. ges. Physiol. (Pflüger), Vol. 122, 1908.
(2) Bryan-Robinson, 1734: quoted by (2a) Müller, Die Massenverhältnisse des menschlichen Herzens, Hamburg and Leipzig, 1882; and by Hoesslin, Arch. f. (Anat. u.), Physiol., 1888.
(3) Parrot, Uber die Grössenverhältnisse des Herzens bei Vögeln, Zool. Jahrb., Vol. 7, Syst., 1894.
(4) Buchanan, On the Frequency of the Heart-beat in the Mouse, Proc. Physiol. Soc., November, 1908. Journal of Physiology, Vol. 37.
(5) ——, On the Frequency of the Heart-beat, etc., in Birds, Proc. Physiol. Soc., March, 1909. Journal of Physiology, Vol. 38.
(6) ——, On the Electro-cardiogram, Frequency of Heart-beat, etc., in Reptiles, Proc. Physiol. Soc., December, 1909. Journal of Physiology, Vol. 39.
(6a) ——, The frequency of the Heart-beat in the Sleeping and Waking Dormouse, Proc. Physiol. Soc., June 18, 1910. Journal of Physiology, Vol. 40.
(7) ——, Results of hitherto unpublished observations and experiments made in Oxford with the aid of grants from the Government Grant Committee of the Royal Society.
(8) Bergmann, Ueber die Grösse des Herzens bei Menschen und Thieren, Inaug. Dissert. München, 1884.
(9) Joseph, The Ratio between Heart-weight and Body-weight in various Animals, (Journ. Exp. Med., Vol. 10, No. 4, 1908.
(10) Martin, C. J., Thermal adjustment and respiratory exchange in Monotremes and Marsupials, Phil. Trans. B., Vol. 195, 1902.
(11) Hering, Ueber d. Beziehung d. extracardialen Herznerven zur Steigerung d. Herzschlagzahl bei Muskelthätigkeit, Arch. f. d. ges. Physiol. (Pflüger), Vol. 60, 1895.
(12) MacWilliam, On the Influence of the Central Nervous System on Cardiac Rhythm, etc., Proc. Royal. Soc., Vol. 53, 1893.
(13) Franck, Anatomie der Hausthiere.
(13a) Forbes, Proc. Zool. Soc., 1881, p. 960.
(14) Haldane, Journal of Physiology, Vol. 18, 1895; Trans. of the Institution of Mining Engineers, vol. 38, 1910, and other papers there referred to.
(15) Bowen, A Study of the Pulse-rate in Man, as modified by muscular work. Contributions to medical research, dedicated to Victor Clarence Vaughan, Michigan, 1903.
(16) Pembrey and Hale White, Regulation of Temperature in Hibernating Animals, Journ. Physiol., Vol. 19, 1896; or (16a) Pembrey's article on Animal Heat in Schäfer's Text-book of Physiology, 1898.
(17) Pembrey, Respiration and Temperature of the Marmot, Journ. Physiol., Vol. 17, 1901.

THE NATURAL HISTORY OF THE SOLITARY WASPS OF THE GENUS SYNAGRIS.[1]

[With 4 plates.]

By E. Roubaud.

The solitary wasps of the subfamily Eumeninæ which belong to the genus *Synagris* inhabit the whole of Africa except the northern portion and Egypt. They are closely allied to the genus *Rhynchium*, but are distinguishable by the labial palpi, which have only three joints, the very long labrum, and the maxillary palpi of 3, 4, or 5 joints.[2]

The systematic relationships of this group, although elucidated by the early investigations of De Saussure, are still imperfectly known, while the biological data which we possess regarding them are much more fragmentary. We know that these insects build nests in the ordinary manner of the eumenids, but their larvæ are little known and their mode of feeding and their history still less.

During the leisure hours of my sojourn in the Middle Congo as a member of the commission for the study of the sleeping sickness, I sought as far as possible to supply some of these deficiencies in our knowledge. The wasps are quite common in the lower Congo, and I found there three species, *S. calida* L., *S. sicheliana* Sauss., and the most common as well as most remarkable of all, *S. cornuta* L. These three species nest by preference on the roofs and walls of houses, at all times, both in the dry or cold season and in the rainy or warm season. There was, therefore, at my very door an interesting subject and one relatively easy to follow and to study from a biological standpoint. Since it had to do with the eumenids, one might have expected a mode of life but little different from that of other solitary wasps—that is to say, an ordinary provisioning of the nests by means of fresh paralyzed prey, with which the egg is shut up and left en-

[1] Translated by permission from Annales de la Société Entomologique de France. Paris, July, 1910. Vol. 79, Pt. I, pp. 1–21.

[2] I owe all the bibliographical details, the information regarding classification, and the exact identification of the species which are the object of these observations, to my friend, Viscount R. du Buysson, whose knowledge and courtesy have been unfailing. I am happy to express here my very sincere thanks.

tirely alone. Observation was not long in demonstrating to me that instinct among these wasps assumed an entirely different form—that throughout the genus it is in full course of evolution toward a higher type, toward the mode of rearing the young so entirely different, which exists among the social wasps. The species of *Synagris* constitute, biologically, a type intermediate between those of the solitary wasps and the social wasps. I shall attempt to show this in presenting the results of my investigations regarding the three species of the Congo. I have been aided in this work by the devoted zeal of my assistant in the commission, Mr. Weiss, to whom I wish to express at the outset my deep sense of gratitude.

Synagris calida L.

This species is not common at Brazzaville. I found only one large nest, which was built in September under the roof of the laboratory of the commission. When collected in October, this nest measured 12 centimeters in length and about 8 centimeters in greatest diameter. It had the appearance of an irregular mass of earth, without appreciable symmetry, the surface being mammilated by a peculiar rough plastering, in which could be recognized the innumerable pellets of earth which the builder accumulated for its construction. This nest contained 11 cells, with very thick walls, all closed and occupied by young pupæ, or by larvæ which had already devoured their food and spun their silken cocoons. Like those of all the species of *Synagris*, this nest was built of a mixture of yellow clay and sand, mixed with saliva. In accordance with the habits of the eumenids, it is probable that each compartment was constructed separately, and that the common covering of earth was merely a secondary assembling of the separate cells. Mr. G. Vasse brought to the Museum of Paris from Mozambique a young nest of this species which consisted as yet only of the first cell. The nest is somewhat conical, and about 5 centimeters long and 4 centimeters across the widest part of the base. The apex is occupied by a large orifice, slightly turned toward one side. Mr. Chevalier also sent one from Krébedjé (Fort Sibut), in the Gribingui, which was already finished and quite old, but which contained only six compartments, from which all the adult insects had gone. It measured 7 centimeters in length and 5 centimeters in breadth.

I should have known scarcely anything about this wasp if I had not accidentally found in one of the closed compartments of the nest which I collected at Brazzaville a young larva dead and desiccated, with the whole of its store of caterpillars. All the other occupants of the cells were either fully developed larvæ which had devoured their food and spun their cocoons, or were pupæ. The caterpillars

found by the side of the young larva of *Synagris* were identified by Mr. P. Chrétien as those of hesperids. By means of these remains it is possible to describe the habits of the wasp. It deposits in the cells during the course of their construction a hoard of caterpillars, rendered immovable, and an egg, and then walls up the orifice, and takes no farther care of its offspring. This is the ordinary provision of food as found among other solitary wasps. Mr. Maindron,[1] moreover, observed in 1879, at Senegal, the mode employed by *S. calida* in providing food. He saw the insect hunt about small bushes, seize upon caterpillars, grasping them with its mandibles and piercing them with its sting, and then carrying them away and storing at least six in each cell. In the Brazzaville nest the number was much larger. I counted as many as 14 caterpillars in the same cell. Many of them were parasitized by the larvæ of a *Tachina* (*T. fallax* Meig. =*T. xanthaspis* Wiedm.=*Eutachina wiennertzi* B. B.),[2] the pupæ of which, having escaped from the host, were found at the bottom of the cell. It is quite possible that the premature death and decomposition of the parasitized caterpillars had led to that of the others, as well as to that of the *Synagris*. The parasitism of the *Tachina* had, therefore, extended its results not only to the hesperid caterpillars, but also to the larva which was to feed on them. This circumstance shows one of the defects in the primitive mode of rearing the larvæ.

Synagris sicheliana Sauss.

It is not the same with *S. sicheliana* Sauss., in which the feeding instinct is perfected, as will be seen presently, in a remarkable manner. This species, which builds nests cell by cell, of rude structure, much resembling those of the preceding species, is the most common form of *Synagris* at Brazzaville. The nests are masses of yellow earth, the surface of which bears the marks of the successive balls of earth which the wasp has joined together to form the cells. The maximum number of cells which I found in a single nest did not exceed eight, and the whole structure was roughly ovoid. The most recent cell is nearly always open, and serves as a shelter for the builder, which very often dies in it. As is usually the case, the materials that serve for the construction of nests are obtained in moist places, mixed with saliva, and carried with very great zeal to the place chosen, which is nearly always under the high roof of houses.

The initial cells are higher than broad and roughly conical. Quite often the earth of old nests is used, in which case they are gnawed and demolished all about the orifice; but I have never observed that

[1] Monit. du Sénég. et Dep., Apr. 15, 1879 (communicated by Mr. J. Künckel d'Herculais).
[2] I owe this identification to the kindness of my learned friend Dr. J. Villeneuve.

a *Synagris* obtained its materials at the expense of fresh nests that were still occupied. The nests were 8 to 9 centimeters long and 7 centimeters broad; the height of the cells, 4.5 centimeters.

Association of nests.—Sometimes the nests are associated, several being placed side by side, so that they form bands of earth 20 to 25 centimeters long, according to the number of individual nests. The number can be ascertained by observing the constrictions in the mass of earth which mark the area of contact between two different nests. (Pl. 2.) Are these fortuitous associations of nests of different age grouped by adult wasps which had no original connection with each other; or are they constructed by females born in the same nest? It is difficult to decide. It appears, a priori, not impossible that they represent the first step toward a grouping in colonies.

Rearing of larvæ.—On February 19 I discovered under the roof of a farm building a nest of this *Synagris*, with two cells. The older, the orifice of which was walled up with a plug of earth, contained a larva already well grown, and a provision of six inert caterpillars, one of which was about three-quarters eaten. In the more recent cell, which was guarded by the female, was found a single yellowish egg merely placed in the bottom of the cell. On the 22d of February another nest was pointed out to me by natives on the quarters of the Senegal tirailleurs. I had it brought down with the greatest precautions. It was an association of nests forming a band that measured about 30 centimeters in length. The adults had already taken their flight, as these nests were old. In two of the cells were found only a couple of females, probably the builders, who had retired within them to die. The last cell alone, at one end of the assemblage, was guarded by a living female. I found there an egg that occupied the bottom of the cell and above it 5 large hesperid caterpillars.

On the 23d of February a third nest was brought to me by a Bakongo boy, who had obtained it on his quarters. Three cells were walled up and contained a young pupa and two full-grown larvæ. A fourth cell was open and contained a wasp with its head turned in a menacing attitude toward the opening. It had not abandoned the nest while the latter was being transported. On turning it out, I found in the cell 10 large hesperid caterpillars, to serve as provision for a large larva which had already attained three-fourths its full size.

On the 27th two nests were brought to me with the greatest care by natives. One consisted of three cells, of which two were closed. The third harbored a young larva with a provision of eight caterpillars. The other nest comprised five cells. In the freshest one, which was guarded by the female, was found an egg without provision. In one of the adjoining cells, which had the orifice closed,

there was a larva of large size with a provision of seven caterpillars, two partly devoured.

With the aid of the foregoing data, it is possible to contruct a history of this *Synagris*. The wasp lays an egg in its cell of earth. Then, without haste, after having guarded it for some time, commences to collect a small provision of caterpillars for the moment of hatching. When the larva has commenced to feed, the *Synagris* continues its provisioning, but in a slow and regular manner, taking care only to furnish its larva with a little more food than is necessary for the day. It is a progressive provisioning, from day to day, which gives the wasp the necessary leisure to guard the larva and watch its growth. A fact of this kind has never before been recorded of the solitary wasps.

When the larva has attained three-fourths of its size, the wasp incloses it in its cell with the last provision. At this time the larva is still transparent and rose colored. In three days it devours the caterpillars at its disposal, takes on a uniform yellowish color, and loses its transparency on account of the abundant development of reserve nutriment. After three days of rest, during which it remains inert and without movement, it spins the thin walls of silk which surround it, and outside of which are left the alimentary wastes, the excrement of the caterpillars, and the hard chitinous parts which have not been devoured.

From 19 to 23 days intervene from the time when the larva spins its cocoon to the time when it emerges as the adult insect. The pupa, properly so called, exists for about 12 days. Thus, three larvæ which spun their cocoons on February 19, 22, and 23, respectively, were transformed into pupæ on March 1, 3, and 5. The adults came out on March 10, 15, and 18. The duration of the pupal stage was, therefore, 10 days for the first, 12 days for the second, and 13 days for the third.

The caterpillars which the female wasps choose for the nourishment of their larvæ are those of various species of hesperids (skippers). I did not observe either their capture or the method of rendering them immobile. Some of them were bitten on the side of the head, and the majority showed indications of having been stung several times. They were always more completely immobile than the caterpillars made use of by the solitary wasps of the genus *Odynerus* in our country. Fabre has observed as regards the latter that the caterpillars, although stung, do not remain motionless, and that they would crush the egg by their movements if it were deposited in their midst. Hence the utility of the suspensory thread which attaches the egg to the surface of the cell in different species of *Odynerus* and *Eumenes*. Ferton mentions that in the case of nests which he observed the caterpillars were possibly able to spin cocoons and to trans-

form themselves. It is far from being so in the case of the caterpillars rendered immobile by *Synagris*, which lie quite inert in the earthen cell and scarcely show any signs of remaining alive, beyond slight movements of the mandibles and head.

The egg is deposited beside them, and is not fixed to the wall of the nest by a suspensory thread, although this thread still exists attached to one end of the egg. The egg, furthermore, is not fixed to the prey, as in the case of such predaceous wasps as *Bembex*, *Oxybelus*, *Ammophila*, *Pompilus*, etc. It is deposited in the bottom of the cell, which is at the time empty, and the female watches for the hatching in order to begin provisioning. This is, therefore, the habit of social wasps. One of the wasps, *Monedula punctata*, has nearly the same habit, according to Mr. Hudson (*ex* Bouvier, p. 26). This wasp digs a hole, deposits its egg therein, and then closes the hole and waits for the hatching of the young larva before undertaking the provisioning. But, as Bouvier has remarked, this proceeding hardly constitutes a marked advance in the evolution of instinct. The young *Bembex*, at its birth, finds itself immured in an empty cell. It does not find at its door the food that it needs after hatching. One can understand, however, the protection of the egg which is assured in this way against the attacks of the Tachina flies. The proceeding of our *Synagris* is much more perfected. The wasp does not wall up its cell after laying the egg. It remains there itself and guards the egg—its head directed outward, thus preventing the access of parasites. On the other hand, it begins provisioning at such time as will enable the young larva, after hatching, to be certain to find its food. The provisioning which then takes place regularly and in proportion suitable to the size of the larva, permits the *Synagris* to watch the growth of its young. This is certainly an important advance over the primitive mode of rearing the young found among the solitary wasps. The larva is not walled up in the cell, which is abundantly supplied with caterpillars, until it has reached a period of active growth, which guarantees, to a certain extent, a favorable termination of its evolution.

The usual mode of provisioning, in which the egg is abandoned to itself in the midst of an abundant supply of caterpillars, is manifestly imperfect. It may happen that the prey which has been collected at one time in a single locality may be already infested with parasites. In this case, these caterpillars, which are in such a condition that they can offer little resistance, soon perish and decompose, involving the death of the larva which they should serve as food. It may happen also that their tissues having been partly devoured by their parasites, the amount of food is insufficient for the complete growth of the young wasp. This occurred, as we have seen, in the case of at least one of the larvæ of our *Synagris calida*. Such an

accident could not happen in the nests of the *Synagris sicheliana*, or at least it could not occur so readily, as the cell is not walled up until late. In this respect, therefore, the slow and progressive provisioning constitutes an indisputable improvement on the primitive instinct. It is an important step in the evolution of the hereditary habits of the solitary wasps.

Synagris cornuta L.

In a third species of *Synagris*, *S. cornuta*, we find the expression of a maternal feeling infinitely more definite, an instinct for rearing the young still more perfected. This is the third term of the series which will lead us directly to the remarkable rearing habits of the social wasps.

Nidification.—The nest of *S. cornuta*, as in the case of the other species, is built by the female, with a yellow earth, a mixture of clay and sand, taken from the borders of brooks in moist places and mixed with saliva. Occasionally the clay chosen is of a gray color. As usual, the male does not participate in any manner in the construction of the nest.

The different cells, in this case also, are built separately, but at periods which may vary considerably more than for the other two species, on account, as we shall see later, of the peculiar manner of rearing the larvæ. The nest is composed of an assemblage of cells which are built separately, but the general structure reveals talent which is unquestionably more perfect than in the other two species. The nest of *S. cornuta* has scarcely been mentioned except by E. André (1895), who described it very briefly. I have had occasion to observe numerous nests of this species in the Congo where it is seen more frequently than the preceding ones. It builds, moreover, in much more accessible places, under roofs of huts (paillottes), and on the protected walls of dwellings of Europeans, at a little distance above the ground. I was able on one occasion to observe the construction of a nest, which was immediately before my eyes on the wall of the laboratory, about 1.50 meters above the ground.

The first compartment took the form of an oval cell, the bottom of which was slightly more expanded than the part which contained the entrance. Usually there is a short neck near the orifice which is more or less inclined toward the side, to facilitate the entrance of the builder. The prominence of the neck is variable. When it is well developed, the cell may take on the appearance, roughly, of a turbinated shell of a gasteropod. (Pl. 3, fig. 2.) Frequently, the neck is lacking, and the entrance is then at the upper part of the cell. The length of the cell is, on the average, 3 centimeters, and the broadest part 22 millimeters. The wall of earth is much less thick in this species than in the case of nests of the other two species of *Synagris*

already mentioned. The materials are noticeably economized, which indicates a constructive ability more certain and more refined. The coating of earth is diversified externally by a multitude of transverse, parallel corrugations, which correspond to the bands of successive accretions during construction. At a distance the whole structure presents the appearance of a small rude basket.

The construction of the cell is begun at the bottom. The wasp molds its work, building up the earth in regular fashion around the whole breadth of the cell. It deposits its material on one side in contact with the substratum. Then, moving backward, it distributes the whole evenly as regards thickness, according to the predetermined diameter of the structure. It carries on this work with extreme care and zeal, interrupting its toil as mason and architect only to go hastily to gather new materials, which, as a rule, it gathers in a single spot. Two or three days are necessary for the *Synagris* to complete its basket of earth. Then the work is suspended for a time. The wasp lays an egg in the cell, and the new occupations of mother and nurse follow that of worker in clay. When the larva, which is born and develops in the cell, has completed its growth, the insect closes the orifice of the cell with a cover of earth, the material for which it frequently takes from the walls of the entrance passage, or neck, so that the opening is often transferred to the end of the main axis of the cell.

The task being finished, the insect returns to its labors of construction, goes to look for suitable materials, and builds a new cell at the side of the preceding one, and in the same form. The maximum number of different cells which may compose the aggregate of an old nest appears not to exceed six, on the average, for a single female. Every time that a new cell is built, it is attached firmly to the preceding ones, and a mass of earth filling the interstices conceals in part the original distinctness of each cell, and also frequently covers the bands of the fundamental coating. The uniting of the different cells, however, is never so complete and never produces so compact a mass as in the case of the nests of the preceding species of *Synagris*. The appearance of the nest is quite different.

The arrangement of the cells in an old nest, and consequently the general form of construction, varies according to the orientation of the whole. Most commonly the successive cells are placed in juxtaposition in a linear series, in a single row along the substratum. The complete nest formed by this manner of assembling takes the shape of a band of earth more or less regular and compact, about 6.50 centimeters in breadth for a nest of four cells, and 3.50 centimeters in height (pl. 3, fig. 3). The different cells are often recognizable only by the orifices, which are all arranged on the same side, whether open or closed. The nests with the cells in a single row are the most

regular and perfect. In their construction the powers of *S. cornuta* in comparison with those of other species are most fully revealed. In other instances the cells are placed one upon another in several rows, the orifices being sometimes in the same direction and sometimes distributed at random. The mass which fills the intervals between the cells may produce a compact and amorphous nest.

The dimensions of these compact nests, which are always less than those of other species of *Synagris* for the same number of cells, the greater thinness of the walls, and the difference in the ornamentation of the outer coating, enable them to be readily distinguished.

Orientation of the nests.—The orientation of the orifice of the cell is variable, as well as that of the whole nest. The wasp knows how to modify slightly, according to circumstances, the general direction which is suitable for the cells. It adapts its constructions to the different conditions existing where the nests are placed. The linear nests are ordinarily placed horizontally if the breadth of the foundation permits and the openings of the cells occupy the highest point. In other cases, especially when a nest is placed on a strongly inclined surface, such as the underside of a roof, the orifices are turned a little more outward. The length of the entrance passage, or neck, and the position of the orifices vary according to the inclination of the foundation. When a nest is fixed to the lower surface of a horizontal wall the entrance to the cells looks downward (pl. 3, fig. 2) in accordance with the development of the neck. Sometimes, though rarely, the wasp nests in the bushes away from habitations. It may then use as supports for its cells the broad and firm leaves of certain herbaceous plants, but it takes care to conceal the nest on the underside of the leaves which, being bent downward by the weight, form a roof for it. When the nest is attached to a narrow leaf, the breadth of which scarcely exceeds the maximum dimensions of a single cell, the orientation of the nest is entirely changed. The cells are placed according to the breadth of the leaf and piled one on another. A linear nest results, but is oriented in accordance with the length of the blade, the orifices of the cells being placed laterally. These facts show a certain elasticity in the manifestations of the constructive powers of *Synagris cornuta*, which we did not find in our other two species.

Ovulation and rearing of the larva.—When the *Synagris* has finished the construction of its cell of earth, it lays a bluish egg, measuring 6 millimeters long, the chorion of which presents at one of the extremities the rudiment of a terminal filament. This is the rudiment of the suspensory thread of the egg, which among a large number of eumenids secures the egg to the wall of the cell. After the egg is laid, the female remains in the nest, her head being turned toward the orifice. She is observed to be absent only for brief periods at long intervals, no doubt leaving in search of food. She does not,

however, bring back any prey, nor undertake any provisioning of the nest. It is only when the larva is hatched that the wasp begins to hunt in a more active manner. She comes and goes incessantly, remaining about the nest only a very short time at repeated intervals. In this respect the habits of our *Synagris* are entirely different, not only from those of the two preceding species, but also from all that is known relative to the eumenids. In examining nests several times shortly after the return of the female—which never appeared to carry living prey in her mandibles—I always found them without provisions of any kind. Whatever might be the age and stage of development of the larva, which lay on its back at the bottom of the cell, it never appeared to have any caterpillars at its disposal. Furthermore, no remains of a previous repast were found, either head parts of caterpillars previously devoured, or excrements of paralyzed caterpillars, such as were always to be seen in the cells of other species of *Synagris*. One is led to conclude that *S. cornuta* forms a remarkable exception among solitary wasps as regards its habits, in that it nourishes its larvæ from day to day, without storing provision for them, and doubtless in a very special manner.

By observing more closely the goings and comings of these wasps I secured the key to the problem. A nest easy of access was examined at the moment when the mother *Synagris* left a cell. I examined carefully the contents of the cell and found therein, as usual, no trace of caterpillars. The larva of the *Synagris* lay at the bottom of the cell. I grasped it lightly by the aid of pincers, and after having confirmed the fact that it showed no trace of food I replaced it in its normal position. Ten minutes later the wasp returned, flying rapidly, and entered the nest. After waiting some moments I forced it to leave the spot and then saw, deposited on the thorax of the larva, on the lower surface near the mouth, a little food mass of a green color and of semifluid consistency, which the larva ate greedily. Looking a little closer, I saw that this food consisted entirely of the rudely worked-up body of a caterpillar.

The manifestation of the feeding instinct of this solitary wasp proves to be entirely different from the stage at which it has arrived in the other two species of *Synagris*. *S. cornuta* nourishes its larva from day to day with caterpillars ground up into a paste which it places close to the mouth of its offspring in the manner so well known among the social wasps.

Thus we find in this species no trace of the primitive provisioning instinct of the solitary wasps. By a sudden leap, we pass to a mode of rearing the larvæ greatly more advanced, which indicates on the part of this species a maternal care that reveals itself only in a very indifferent and primitive form in *Synagris sicheliana*.

The nutritive paste is deposited by the mother wasp on the ventral surface of the thoracic segments of the larva. A slight movement of the head suffices to enable it to reach the food. The larva lies on its back in the cell, and the form of its body, which is more sharply curved than that of the species of *Synagris* (pl. 4, fig. 1), helps to facilitate the contact of the mouth with the food.

The solicitude of the mother *Synagris* for her offspring is very great. She goes almost constantly in pursuit of food, which the larva devours at once. During the day her hours of rest are few, for the growth of the larva is rapid and its appetite insatiable. Hence one sees the female at the nest only at short intervals. She brings food, deposits it in the proper place, remains a few moments engaged in caring for the larva, with the hind part of the body directed outward, turns around, and leaves the nest once more. While she distributes the food she does not appear to manifest her agitation and concern by strokes of the wings, as *Icaria* or *Belonogaster* do when giving food to their young.

Nothing from without shows the nature of the occupation of the *Synagris* when she provides for the needs of her larva. The absences of the female when the larva is full grown are of frequent occurrence but short duration. The extent of her wanderings and the radius of her pursuit of prey must therefore be quite limited. During rare moments of rest and at night the wasp remains in her cell with her head turned outward, guarding her young.

It would be interesting to know how the *Synagris* kills the caterpillars which she distributes to her larva, what use she makes of her sting, and the primitive practice of paralyzing the prey. I was not able to solve these questions. As to the nature of the caterpillars which she captures, it is difficult to determine the species from the food paste itself. However, as far as I was able to judge from the form of certain parts of the anal region still recognizable, as well as from the green color of the mass, they are probably skippers (Hesperidæ), like those chosen by the other species of *Synagris*.

When the female has decided that the growth of the larva is finished, she walls up the orifice of the cell with earth, and, ceasing thereafter to occupy herself with the prisoner, thinks immediately of the offspring which should succeed him. She goes back to the original work of mason and builds at the side of the closed cell a new one of the same type, which is immediately joined to the former. Afterwards a secondary coating is used to consolidate the whole structure, especially if the cells are already numerous. Their individuality is thus obscured.

The new larva which hatches in this cell is nourished in the same manner as before. In the meanwhile the preceding larva, in his walled-up cell, after remaining inactive for some days, covers the

earthen walls with a thin layer of silk and becomes transformed into a pupa.

At the time when the cell is closed and when, consequently, the feeding of the larva terminates, the latter does not appear to have entirely lost its desire for food. It devours eagerly all the animal prey which is offered to it. This makes it necessary to conclude that the mother wasp has a special instinct which leads her to suspend the alimentary functions of the larva at the proper time. We shall see presently, indeed, that under certain circumstances she herself delays the closing of the cell and prolongs for a considerable time the rearing of a single larva. The insect is informed by a very special instinct of the time when she should wean her offspring.

Under ordinary conditions about a month is required by *S. cornuta* to rear her larva from the egg to the closing of the cell in which it is contained. Thus, at Brazzaville my assistant, Mr. Weiss, determined the presence of an egg in a newly made cell on October 29, but it was only on November 26 that the female began to close the orifice of this compartment, having finished the feeding of her larva. I do not know the amount of time which it is necessary to deduct for the development of the egg in order to arrive at the exact duration of the larval life to the end of feeding. This period should, moreover, vary a good deal according to the abundance of the nourishment which the larva receives. Nests of four cells are frequently found in which the first three cells are walled up, while the female has already begun the rearing of a fourth larva and no hatching of the adult has yet taken place. Since as it is necessary to count 20 days from the closing of the cell to the hatching of the adult there is reason to believe that the larval growth was very rapid in such cases, as the three larvæ were reared before the end of the period.

At the laboratory of the commission at Brazzaville, I followed the history of a nest which was begun under my eye at the beginning of July. This nest, which was built by a young female, was limited to a single cell until October 20, when the female decided to wall in the larva and begin the construction of the next cell. During more than three months, therefore, the wasp was occupied in nourishing and caring for the same larva. I frequently saw it on the nest, assuring itself of the solidity of the cell, and inspecting the surroundings, evidently concerned by the necessity of walling up the first cell and building another to receive the second egg. I found an explanation a little later of the exceptional length of this particular period of rearing a larva.

On November 26 I opened the cell, which was closed at this time, and found the place of the pupa occupied by a parasitic ichneumon-fly. The slow growth of the infested *Synagris* was thus easily explained. From the facts mentioned, the conclusion must be drawn

that the female *S. cornuta* possesses the power of regulating the time of laying her eggs or at least of retarding the process considerably for the benefit of the larva which she nourishes and cares for. She devotes herself to it entirely and does not abandon it in spite of the slowness of its evolution until she knows that it no longer needs her services.

In this particular case the retardation produced by the parasite in the development of the first larva proved fatal to the whole subsequent progeny. The mother *Synagris*, after having finally walled up the first cell, commenced the construction of the second nearly three and a half months after the former. After a day of toil she disappeared and did not return. It is probable that she perished through accident and with her all the future line. This was the indirect result of the action of the parasitic ichneumon-fly on the first larva, which occupied uselessly in its behalf the greater part of the life of the female.

It is possible, of course, that the latter, warned by the presence of the parasite, summoned courage to begin a new nest elsewhere, but the fact that she had commenced to build a second cell (at the original nest) renders this hypothesis improbable.

The duration of the pupal stage in *S. cornuta* is approximately a fortnight. From one cell, which was closed on December 13, an adult emerged on January 5—after 23 days. It is necessary to deduct from this period the time necessary for the larva to spin its cocoon and transform itself into a pupa, which may be reckoned as about a week. In order to escape from its prison of earth the adult *Synagris* moistens with saliva, in the usual manner, the ball of earth which closed the cell, and the latter, softened immediately by absorption, yields at once to the pressure of the captive wasp.

The males.—Following in this respect the habits of other Hymenoptera, the males of *Synagris cornuta* take no part in the protection or construction of the nest or in the rearing of the young, notwithstanding the threatening armor of their mandibles. However, they do not remain entirely ignorant of what passes; they inspect the young and visit them daily. Under the roof of a hut at Brazzaville Mr. Weiss and I noticed several nests of *Synagris* fixed in different places and sufficiently difficult to find to require search for some moments in spite of certain indications. One day I noticed a large male of this species which flew about slowly, examining the nests successively, moving with certainty and without any hesitation toward each of them as if it had known for a long time the exact location of each. It stopped for a moment on a nest, disregarding the open cells and touching and examining preferably the cells still walled up, which contained pupæ. This male evidently came to watch the emergence of the young females, and the exact knowledge

which he possessed of the distribution of the nests leads one to believe that he came out of one of them and returned frequently to the place of his birth. At my suggestion, Mr. Weiss caught this male and in order to recognize him removed his left posterior tarsus. Then he was set at liberty again. For some days the insect, doubtless because frightened, did not reappear, but the following week he was captured again just as he was returning to make his usual inspection. It may be said, therefore—and this is a character which distinguishes this species from all other eumenids—that the males of *Synagris cornuta* are not entirely indifferent to the work of the females; that they know all the nests that are to be found in a given area; and that they visit them regularly, doubtless for the purpose of seizing the females when they emerge. Except for these brief visits, the males are never seen about the nests. They wander at will outside of habitations in the bush and build no shelter for themselves.

When two males meet on the same nest they attack each other with open jaws, repel each other with their large pincers, and strive to thrust one another away. The first comer usually maintains the advantage. It is principally for this that the formidable pincers, which are developed on the mandibles, as in the stag beetles, seem to serve. They are probably secondary sexual characters rather than real organs of attack and defense developed by sexual selection, which give those who have them an authority over the nests, and consequently possession of the young females. It is probable, also, that they play some rôle in copulation. Nothing is more variable among the individuals reared in the same nest than the size and form of these large pincers. Some males are entirely without them; others have them narrow and short, but very sharp; while in others again they reach extraordinary dimensions and are provided with a blunt tooth near the middle. They represent a sexual character which is not yet fixed, over which hovers the mysterious phenomenon of variation.

It is well to remark that this section of the genus *Synagris*, which is very sharply differentiated from the others by the form of the mandibles in the males, is also completely separated by these biological characters. It is extremely probable that the mode of feeding the larvæ with fragments, which is exhibited by *S. cornuta*, occurs among the other species of the same group. Viscount du Buysson (1909) has quite recently made known a nest of *S. didieri*, a new species from the Congo, which belongs to the section of *S. cornuta* L. and *S. proserpina* Grib. This nest is precisely like that of *S. cornuta*. From one of the compartments Mr. Didier extracted a larva which was isolated in its cell without any débris of caterpillars which had served as food around it, such as are always found in the case of those forms which do not feed their young with fragments. It may be

affirmed, in my opinion, without hesitation, that this species is biologically of the same group as *S. cornuta* L.

Evolution of instinct among the solitary wasps.—The biological history of the species of *Synagris* permits us to see, within the limits of a single genus, instinct developing from the provisioning in mass characteristic of the ordinary type of eumenids to continuous provisioning, and finally to the feeding of the larvæ from day to day after the mode of the wasps which live in colonies. We find combined in a singular manner in the same type of wasps the principal steps which lead from the primitive instinct of the solitary wasps to the much more perfected instinct of the social wasps.

By reason of the facts which we have brought forward, it should not be thought that the habit of nourishing the larvæ from day to day on caterpillars ground into a mass, which is customary among the social wasps, may represent a primitive mode of provisioning peculiar to wasps which do not know how to make use of the sting to paralyze their prey. It is, on the contrary, manifestly a modified form of the instinct of provisioning found among the wasps that paralyze their prey which forms a complete substitute for these hereditary habits, while at the same time maternal attachment and caring for the progeny are developed.

This conception is a little different from that of Bouvier (1901), who regarded the habits of the social wasps and the solitary wasps as derived from a common source, this source being a species with the habits of *Monedula punctata*, which kills its prey without paralyzing it and provisions its nest continuously from day to day. Hence, the habits of these wasps are to be regarded as having developed in two different directions, the social wasps preserving the habit of killing their prey and provisioning the nest continuously (with slight modifications), the solitary wasps acquiring, on the contrary, with the habit of paralyzing their victims, the possibility of provisioning the nest all at one time. The evolution of instinct in *Synagris*, which we have been able to follow, leads to different conceptions as regards the wasps. Feeding the young by mouthfuls with caterpillars ground up into a paste represents the last term of an evolution of the rearing instinct the initial form of which is a slow, progressive, and continuous provisioning with paralyzed prey, which permits the mother wasp herself to watch the growth of her offspring.

In the mode of rearing the larva so highly perfected in *S. cornuta* may be seen the direct bond of union between the solitary wasps and the social wasps. To understand how the final stage of evolution is reached by the latter it is only necessary to observe the colonizing tendencies among the solitary wasps, which employ continuous provisioning and nourishing their young by mouthfuls. We have already noted in *Synagris sicheliana* the association of nests, which is also

frequently found in *S. cornuta.* One may be permitted to see in these aggregations the beginnings of association in colonies, such as different authors have observed; for example, in *Polistes* (Marchal, 1900; Ferton, 1901). It is difficult to say whether these associations are purely and entirely due to chance; whether the different grouped nests are made by individuals which are strangers to one another; or whether they are not rather made by individuals from a single nest which build their cells in proximity to those in which they are born. If this hypothesis has not yet been directly verified, it has at least the appearance of great probability. One may advance in its favor the instinct of knowledge of places which leads the males of *S. cornuta*, for example, to return frequently to the same nests and watch them closely. It may be asked why it is not the same as regards the females, and whether they may not possess some tendencies to build by preference in the vicinity of the nests in which they were born. We firmly believe that such is the fact, and that certain of these associations may be interpreted as the first step in the evolution of the instincts of the solitary wasps in the direction of those of the social wasps.

Parasites of Synagris.—The nests of *Synagris* may be invaded by different insects, some merely commensals which use only the cells of old nests in which in their turn to rear their young; others, genuine enemies that seek the larvæ of *Synagris* in order to prey on them. The usual commensals of the nests of *Synagris* are sometimes solitary bees of the genera *Megachile*, *Osmia*, etc.; sometimes spider-wasps (Pompilidæ). The majority of old nests are occupied by these hymenoptera, sometimes isolated, sometimes associated in the same nest. Occasionally the nest of the spider-wasps is made on the cells previously occupied by the solitary bees.

One of the most formidable parasites of *Synagris* is an ichneumon-fly, *Osprynchotus flavipes* Brullé. This insect has a wide distribution in Africa. The Museum of Paris contains specimens of it from Dakar, Casamance, Mozambique, British East Africa, the Gaboon, and the valley of the Zambezi. The larvæ of this ichneumon-fly (pl. 4, fig. 2) infest those of several species of *Synagris.* I have obtained them from *S. cornuta* and *S. sicheliana.* It is probable that they attack all the species. We have called attention above to the disastrous effects as regards the development of the whole of the later progeny of the wasps, due to the attack of *Osprynchotus* on the first larva in a nest of *S. cornuta.* The great retardation which resulted in the development of the parasitized larva delayed the building of new cells and prevented the mother wasp, which was entirely devoted to her fated offspring, from rearing new larvæ, that might perhaps have escaped the parasite. Thus, the very per-

fection of this maternal instinct, so highly developed in the species of *Synagris* of the group to which *cornuta* belongs, in this instance spread the inauspicious influence of an isolated case of parasitism over the whole nest, with disasterous results.

In *Synagris cornuta* the instinct, though so much perfected, is inferior, from this point of view at least, as compared with that of the other species which do not follow the practice of feeding the larvæ from day to day in a manner so complete and exclusive. On the other hand, the ordinary provisioning, consisting of blindly burying the egg in the midst of a quantity of food without care of any kind on the part of the mother, also presents, as we have seen, other disadvantages. It is an indirect parasitism which in turn produces unforeseen effects. The caterpillars employed for provisioning may be infested by Tachina-flies, and hence unavailable as food for the larva of the *Synagris*, which is condemned to perish, notwithstanding the deceptive mass of provisions with which it is surrounded.

Another parasite, less common than the last, which has thus far been observed only in the nests of *S. cornuta*, is a magnificent species of beetle of the family *Rhipiphoridæ*, which is also a mortal enemy of the larvæ of this wasp. At present I do not know at what time it penetrates into the cell and begins to attack its prey. Probably it waits until the wasp walls up the cell and feeds on its host only when the latter has ceased to have recourse to the maternal care.

Finally, the adults themselves may be parasitized by the larvæ of Chalcis-flies (small parasitic hymenoptera). I observed at Brazzaville for more than three months a female of *Synagris cornuta* belonging to a nest consisting of a single cell, which remained in its nest without laying eggs, until one day I saw emerge from the extremity of the abdomen, which extended outside the nest, a small white active larva. A few moments later another larva appeared, and, like the preceding one, dropped to the ground. I then captured the *Synagris* and discovered by dissection that the whole body cavity was infested by small larvæ similar to the first ones, which were doubtless prepared to escape by perforating the articular membrane of the posterior segments. These larvæ (pl. 4, fig. 3) were characterized by the presence of four pairs of retractile pseudopods on segments 5 to 8 of the body. I was unable to ascertain the adult form. The larvæ were transformed into pupæ in a small cocoon soon after leaving the body of the host, but they did not emerge.

A noteworthy fact in this instance was the sterility of the parasitized wasp. It was observed to be incapable of laying eggs, and dissection showed that the ovaries remained in a state of immaturity. This was a clear case of parasitic castration. No doubt other para-

sites of *Synagris* also exist, and one may expect to ascertain very interesting facts regarding their life history. It would be desirable to extend the study, which is scarcely more than begun, as well as to confirm the history of the different species of these solitary wasps. The brief researches which I was able to make during my stay in the Congo lead me to hope for considerable discoveries in the future in connection with this subject. I shall be happy to have turned in this direction the efforts of African naturalists.

BIBLIOGRAPHY.

André, E. Sur quelques Vespides africains nouveaux ou peu connus. Revue d'Entomologie, Vol. 14, 1895, p. 352.

Bouvier, E. L. Les habitudes des *Bembex* (monographie biologique). Année Psychologique, 1900.

Buysson, R. du. Monographie des Guêpes ou *Vespa*. Bull. Soc. entom. de France, Vol. 72, 1903.

Id. Hyménoptères nouveaux. Revue d'Entomologie, 1909, pp. 207–219.

Dalla Torre, C. G. de. Catalogus Hymenopterorum, Vol. 9.

Fabre, J. H. Nouveaux souvenirs entomologiques, 2e série, Paris, 1882.

Ferton, Ch. Notes détachées sur l'instinct des Hyménoptères mellifères et ravisseurs, 1re série. Ann. Soc. entom. France, Vol. 70, 1901.

Id. Notes détachées sur l'instinct des Hyménoptères mellifères et ravisseurs, 2e série. Ann. Soc. entom. France, Vol. 71, 1902.

Latreille. Hist. naturelle crust. et insectes, 1802, Vol. 3.

Maindron, M. Moniteur du Sénégal et Dépendances, April 15, 1879.

Marchal, P. Observations sur les *Polistes*. Bull. Soc. zool. France, Vol. 21, pp. 15–21, 1896.

Roubaud, E. Recherches sur la Biologie des Guêpes solitaires d'Afrique du genre *Synagris*. Comptes rendus de l'Académie des Sciences, No. 16. 1908, p. 696.

Saussure, H. de. Mélanges hyménoptérlogiques. Mém. Soc. Phys. et Hist. nat. Genève, Vol. 17, 1863.

Id. Étude Fam. Vespides, I, Euménides, 1852.

EXPLANATION OF PLATES.

Plate 1.

Fig. 1. Nest of *Synagris sicheliana* Sauss. A nest of five cells. Brazzaville. E. Roubaud.

2. Nest of *S. calida* L. Mozambique, Guengère. G. Vasse, 1906, Museum of Paris.

3. Nest of *S. sicheliana* Sauss. A nest of three cells. Brazzaville. E. Roubaud.

4. Nest of *S. calida* L. French Congo, Fort Sibut, Krébédjé. A. Chevalier, Mission Chari-Tchad, Museum of Paris.

Plate 2.

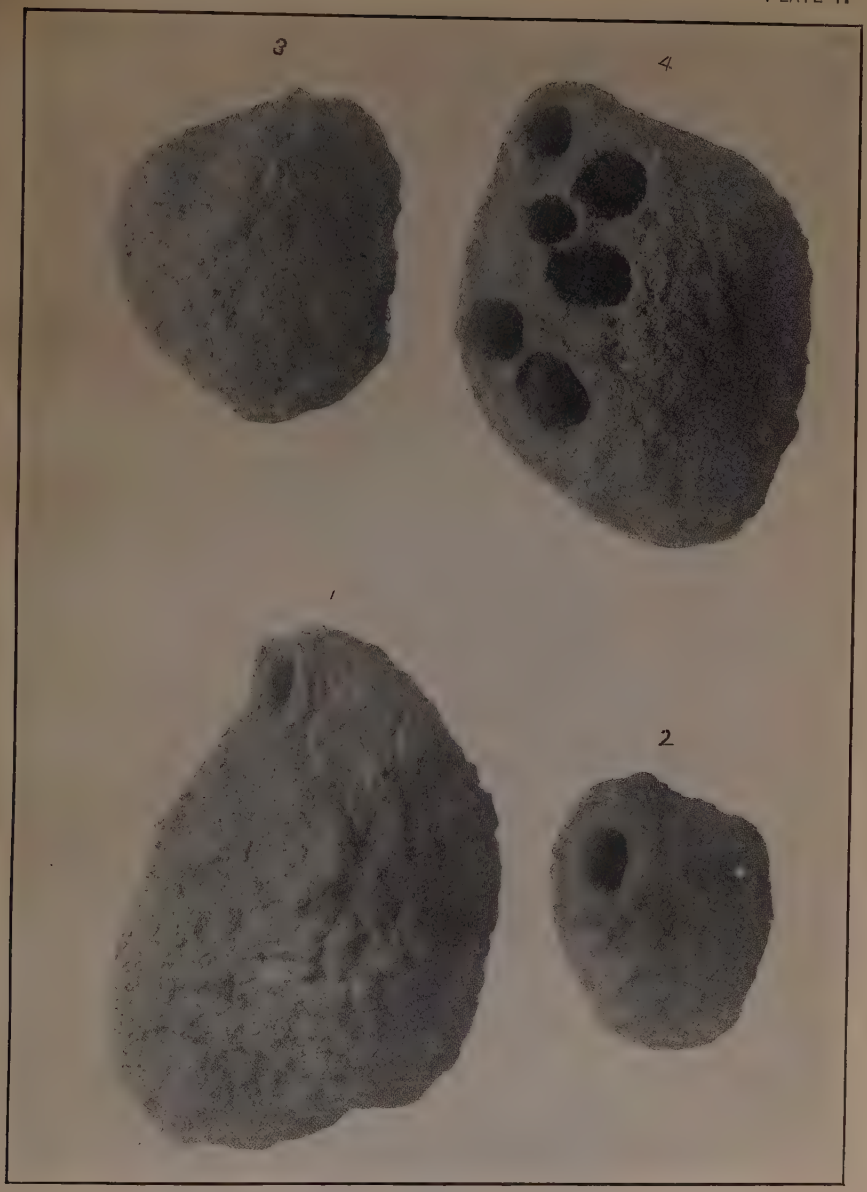
Associated nests of *S. sicheliana Sauss.* Three nests. Brazzaville. E. Roubaud and A. Weiss.

PLATE 3.

FIG. 1. Nest of *S. cornuta* L. A nest of three cells, the binding cement of which has been partially destroyed by commensals after completion.
2. Initial cell of *S. cornuta* L. Congo, forest of Ababouas, valley of the Roubi. Mission of Bourg de Bozas, L. Didier, 1903. Museum of Paris.
3. Linear nest of four cells, of the same species. Brazzaville. E. Roubaud.
4. Complete nest, with cells superimposed, of the same species. Brazzaville. E. Roubaud.

PLATE 4.

FIG. 1. Full-grown larva of *S. cornuta* L. and its food-paste. × 5.
2. Larva of *Osprynchotus flavipes* Brullé. × 5.
3. Larva of the Chalcidid parasite of *S. cornuta* L.
4. Larva of *S. calida* L. × 5.
5. Egg of *S. calida*. × 5.



HISTORY OF SOLITARY WASPS.

FOR EXPLANATION OF PLATE SEE PAGE 524.

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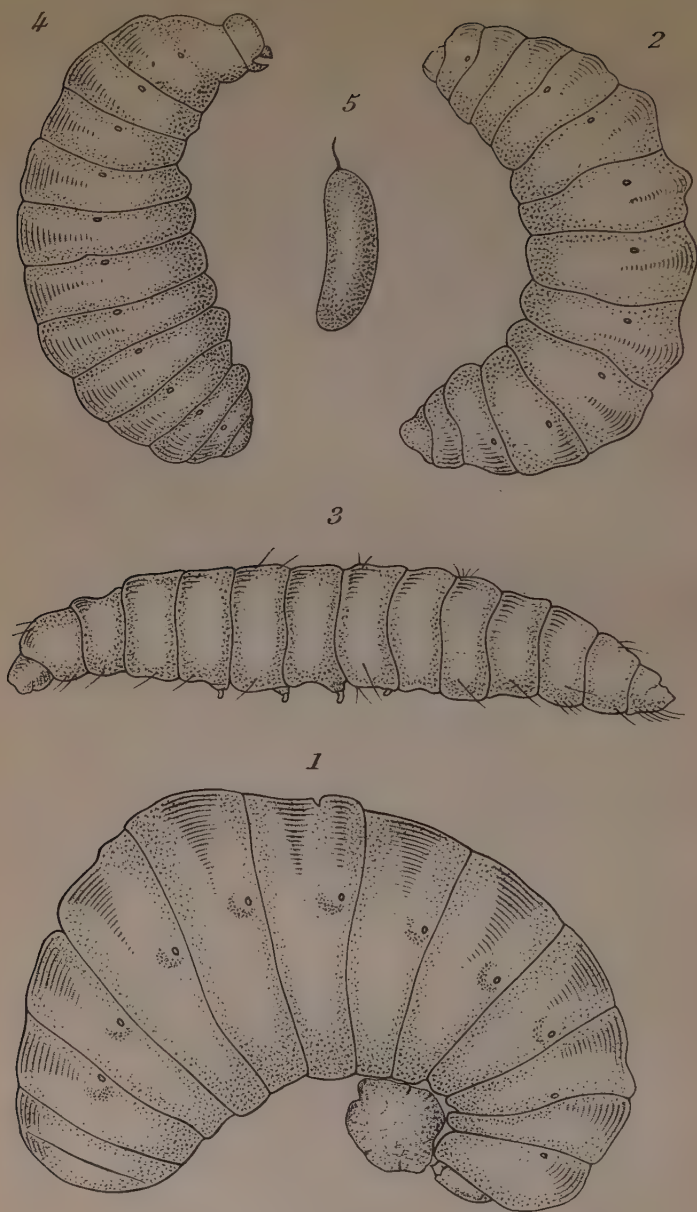


HISTORY OF SOLITARY WASPS.

FOR EXPLANATION OF PLATE SEE PAGE 525.

A CONTRIBUTION TO THE ECOLOGY OF THE ADULT HOATZIN.[1]

[With 7 plates.]

By C. William Beebe.

INTRODUCTION.

The strangeness of life and structure of this bird have made it classic in the annals of ornithology, and because of this claim upon our interest I offer the present article as a résumé of our present knowledge of the habits of the adult hoatzin. We are still ignorant of a considerable part of its life history, although there is small excuse for this, as the bird is sedentary, abundant wherever found, and tame to an absurd degree.

I have had two brief opportunities for observing this species in life, once in March, 1908, on the Guarapiche River in northeastern Venezuela, and again in April, 1909, on the Abary River, British Guiana. On neither occasion were young birds to be found, so my notes refer solely to the adults.

Although it is not my intention to discuss the anatomy of the hoatzin, mention may be made of certain peculiarities which exert an important influence upon its habits and activities.

The crop of this bird is unique in having assumed the structure and importance of the gizzard in other birds. It has increased greatly in size, measuring, when well filled with food, about 2½ inches in diameter. The walls, instead of being flabby and glandular, are thick and muscular. This increase in the size of an organ situated far forward in the body has resulted in a reduction of the front part of the keel of the sternum, a condition unique among birds. In reducing the area of attachment for the pectoral muscles this change has radically affected the power of flight.

In spite of this specialization, there is no doubt that the hoatzin is an extremely ancient and isolated type, and it has very properly been set aside in a separate order by itself—Opisthocomiformes (43). Combining, as it does, the characters of several orders, it is impos-

[1] Reprinted by permission, after author's revision, from Zoologica; Scientific Contributions of the New York Zoological Society, Vol. I, Nos. 2, 3, Dec. 28, 1909, pp. 45–66.

sible to indicate its correct position in a linear classification. In such artificial, two-plane, genealogical trees it has been variously placed between the game birds and the rails; between the pigeons and the rails; while it has certain affinities with the plantain eaters, and the vestigial claw on the third digit links it with the primitive Archaeopteryx.

Another claim to a primitive condition is found in the quadrupedal habits of the young. These, by means of unusually developed fore limb and fingers, and external claws on the first and second fingers, are able to climb actively about the bushes. They also swim and dive well.

HISTORY.

More than 250 years ago Hernandez, in his Nova Plantarum, Animalium et Mineralium Mexicanorum Historia (22), makes the first authentic mention of the hoatzin, writing in Latin as follows:

> The hoatzin, a bird uttering a curious note, sounding like its name.
>
> This is a bird of about the size of an Indian fowl. Its beak is curved; its breast shades from white to buff; its wings and tail are spotted with white at intervals of a thumb's length; the back of the upper part of its neck is yellow, shading into blackish on both sides and sometimes extending as far as the beak and eyes; the claws are black and the legs blackish. The bird bears a sturdy crest of feathers, varying from white to yellowish, the back of each feather, however, being black. The bird subsists upon snakes. It has a powerful voice, which resembles a howling or wailing sound. It is heard in the autumn and is held inauspicious by the natives.
>
> The bones of this bird relieve the pain of wounds in any part of the human body; the odor of the plumage restores hope to those who, from disease, are steadily wasting away. The ashes of the feathers when devoured relieve the gallic sickness, acting in a wonderful manner.
>
> The bird lives in warm regions, such as Yauhtepeceusis, generally establishing itself in trees growing along the banks of the streams, where we, having observed it, captured it, and making a drawing of it, kept it alive.

With the exception of the description, which is fairly accurate, this quotation is interesting chiefly because of its characteristically medieval superstition.

One hundred years after the account of Hernandez, Brisson (11) wrote a vague and plagiarized description of the New World bird which he called Le Hocco Brun de Mexique (*Crax fuscus mexicanus*). He said:

> It is nearly as large as a female turkey. Its head bears a crest composed of feathers which are yellowish-white above and black below. The sides of the head, the upper part of the neck and back are reddish-brown. The breast is yellowish-white. The wings and tail are varied with white and yellow, and that by spots of a thumb's length. The feet are brown and the claws black. It feeds on serpents. It is found in Mexico, and chiefly in the hottest parts. It perches on the trees which are found along the rivers.

The final sentence is admirable, but as the bird is a vegetarian and is not found in Mexico, and as Brisson seemed rather color blind,

little can be said as to the remainder of the quotation, which I offer merely from the interest attaching to very early accounts.

As in the above instance, the inaccuracies of the pioneer ornithologist Hernandez have been repeated, and, indeed, enlarged upon by succeeding authors. Thus Latham (26) 23 years later informs us that the "Crested pheasant" inhabits—

> Mexico and parts adjacent, where it feeds on snakes; makes a howling kind of noise, and is found in trees near rivers; is accounted an unlucky bird. Met with chiefly in the autumn, and is said to pronounce a sound not unlike the word "Hoactzin." We learn from others that it may be domesticated, and is seen in that state among the natives; and further that it feeds on ants, worms, and other insects, as well as snakes.

In 1819, about 60 years after Brisson's account, Stephens (47) vouchsafes the following information concerning the "Hoatzin serpent eater":

> It inhabits Guiana, and is found on trees near rivers; its food consists of grains and seeds; it will also eat insects and serpents; it has a howling, disagreeable note; its flesh has a very disagreeable smell (probably caused by the quality of its food) and is consequently not eaten, but is used by the fishermen to catch certain fishes.

Even the writings of recent observers on the spot, with every opportunity for good observation, are in some instances totally misleading. For example, Penard (34) tells us that hoatzins run rapidly on the ground, swim well, and "leven in groote troepen van honderden individuen."

NAME.

Müller (28) called the bird *Phasianus hoazin*, and although it was soon removed from that genus, his specific name still stands accepted. The name hoatzin, hoazin, or hoactzin, as it is variously spelled, refers to Hernandez's (22) account, of which Buffon (13) says:

> Its voice is very strong, and it is less a cry than a howl. It is said that it pronounces its name (hoatzin) apparently in a sad and mournful tone. It is no longer necessary to make it pass with the common people for a bird of ill omen; and since everywhere a great deal of power is assigned to that which is feared, the same people have thought to find in it remedies for the gravest maladies. But it is not said that they feed themselves on it. They abstain from it in fact, perhaps as a result of the same fear, or because of a repugnance founded on the fact that it makes its ordinary food of serpents. It stays usually in the great forests, perched on the trees along the water, for watching and surprising these reptiles. It is found in the hottest parts of Mexico. Hernandez adds that it appears in autumn, so that it is a migratory bird. Mr. Aublet assures me that these birds become tame; that they are sometimes seen in captivity in the houses of the Indians; and that Francois called them peafowl. They feed their young on ants, worms, and other insects.

Much of the charm of this wholly inaccurate and altogether delightful account is lost in the translation from Buffon's native tongue.

The present generic name *Opisthocomus* was given by Stephens (47), referring to the long, waving crest; *ὀπισθό-κομος*, wearing the hair long behind, or literally, having hair behind. (*ὄπισθεν*, behind, + *κόμη*, the hair.)

Ignoring the various bizarre appellations given to this species by writers of the last century, we may review the common names in use to-day.

Quelch (38) writes 20 years ago: "The hoatzin is known in British Guiana by the various names 'Anna,' 'Hanna,' 'Canje' or 'Stinking pheasant,' and 'Governor Battenberg's turkeys'; but in the districts where it is found the name 'Hannah' is the one most commonly used." In a recent trip to the above-mentioned colony I heard only the name "Canje pheasant" used, although I discussed the subject with people of many classes.

FIG. 1.—Distribution of the hoatzin, as far as known.

Among the Portuguese of Brazil the hoatzin is called Cigana, meaning gypsy, and Catingueiro, signifying odor of the negro. The Dutch of Cayenne speak of these birds as Canje Fazanten, while the more euphonious name of the Venezuelans is Guacharacas de Aqua. They also call it Chinchena, while in Bolivia the hoatzin is known as Loco, or crazy bird.

DISTRIBUTION.

The little we know of its distribution shows that the hoatzin is as remarkable in this respect as in other phases of its life history. Sharpe (45) gives its range as follows: Amazonia, Guiana, Colombia, Ecuador, Peru, and Boliva. This is very misleading, however, for certain factors enter into the question of inhabitable territory which require more detailed reference.

Penard (34), writing of the birds of Dutch Guiana, gives as the local distribution of the hoatzin, "Wouden en terreinen waar *Arum arborescens* groeit." This is certainly not true as regards British Guiana. The great heart-shaped leaves of that Arum are seen along the lower reaches of every coastal river, yet the hoatzins are confined to three streams, two of which are little more than creeks, in the extreme eastern portion of the colony. These are the Berbice, the Canje, and the Abary Rivers.

On the Abary one has to ascend about 20 miles from the coast before hoatzins are seen, and from here on they are scattered at irregular intervals for 8 or 10 miles, confined exclusively to the fringe of bushes on the windward side of the creek. So when we read that the hoatzin inhabits British Guiana, instead of thinking of it as a bird of strong flight, which traverses savannas and forests, we must realize that it is to be found in only the merest fraction of the colony.

Taking again the large area drained by the rivers just north of the Orinoco delta, one finds hoatzins absent except on the Rio Guarapiche, beginning 2 miles below the village of Caño Colorado.

I append a list of the localities from which hoatzins have been recorded. Their isolated character, while doubtless reflecting our faulty and inadequate knowledge, hints also of the remarkably sporadic occurrence of these birds:

Colombia: Bogota, Sclater (40).
Ecuador: Rio Copataza, C. Buckley.
Peru:
- Cashiboya, Scl. & Sal. (42).
- Yquitos, Berlepsch (7).

Bolivia: Lower Beni River, Allen (1).
Venezuela:
- Canõ del Toro, Hornaday (23).
- Orinoco from the delta to Rio Meta, Cherrie (16).
- Aqua Salada, Cherrie (16).
- Angostura, Berlepsch (7).
- Caicara, Berlepsch and Hartert (9).
- Guarapiche River, Beebe (5).
- Rio Guanare, Bingham (10).

British Guiana:
- Estuary of Berbice, Brown (12).
- Berbice, Sclater (41), Quelch (38).
- Abary Creek, Quelch (37), Beebe (6).

Dutch Guiana:
- Maroni River, Perrin (35).
- Indefinite, Penard (34).

French Guiana: Approuague, Berlepsch (8).
Brazil:
- The hoatzin seems to be abundant locally "in the marshy regions which border the Amazon and its tributaries," Goeldi (20).
- Para, Amazon, Rio Negro, Rio Solimoens, Astlett (2).

Brazil—Continued.
Amazona inferior, Est. do Amazonias, Rio Juruá, von Ihering (25).
Santarem, Pelzen (33).
Lower Rio Capim, Goeldi (21).
Obidos, Sclater.
Marajo Island, Rio Anabiju, Bingham.

The lower Amazon may thus be considered as a center of distribution from which the birds have slowly extended northward into the Guianas and the Orinoco region, northwest to Colombia, west to Ecuador and Peru, southwest to Bolivia, and south to the various tributaries of this greatest of rivers. Not one of these localities is separated by a real watershed, and all are in communication with the Amazon either by direct tributaries or by marshy itabos, or river joiners.

GENERAL APPEARANCE.

As far as general appearance goes, the name "pheasant" is not far amiss when applied to the hoatzin. It comes closest in general aspect to the chachalacas, but there is something strongly suggestive of a peacock, especially in the carriage of the neck and head. This is well shown in the positions of some of the individuals in plate 3.

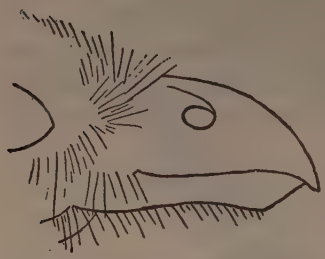


Fig. 2. Beak of hoatzin.

My descriptions are based on 15 adult hoatzins from the following localities: Ciudad Bolivar (9), Guarapiche (1), Bogata (1), Bolivia (1), Peru (1), Amazon (1), Abary, British Guiana (1). There is apparently no distinguishing sexual character and remarkably little variation in size. However, the bird which I collected in the Guarapiche, although adult, is distinct from all the others in color; and if these characters should be found to be constant in other individuals the birds in this isolated locality would form a distinct subspecies.

The beak of the hoatzin is peculiar in shape, and a better idea can be obtained from the outline drawing than from the description alone. The mandibles are deep and wide, the average measurements of 15 specimens being as follows: culmen, 29 millimeters; depth of mandibles at gape, 22 millimeters; width at gape, 19 millimeters. The striking character of the mandible is the shortness of the gonys, this being only about 9 millimeters, or one-fifth of the total length of the mandibles. The mandibles are slaty olive, lighter on the edges. The nostrils are round and placed about midway between the eye and the point of the beak. The sides of the head are almost bare, being covered only with a very scanty growth of black, bristlelike feathers on cheeks, ears, and lores. Two rows of these function as eyelashes.

The bare skin about the eyes is Nile blue in color, shading into cobalt on the other unfeathered parts of the head. The irides are carmine.

The bristles on the upper lores point upward, their tips interlocking on the forehead. Just back of them begins the long waving crest which is such a marked character of this species. The crown feathers are reddish buff; in those on the occiput the buff darkens and becomes a shaft stripe, while the edges and tips of the feathers are black. The longest measure about 4 inches. The feathers of the upper parts as a whole are dark brown, with a distinct olive-green iridescence. The feathers of the nape and neck have pale, buffy shaft stripes, this color changing to white on the mantle. In some specimens the scapulars are margined with white. The outer edges of the thumb feathers are pale buff, corresponding in shade to the feathers of the chin, throat, and breast. Most of the wing coverts are tipped more or less broadly with white, forming three distinct wing bars.

The under wing coverts and primaries are of a rich maroon or chestnut, this hue being duplicated in the feathers of the sides, belly, flanks, and most of the under tail coverts. The tips of the primaries are olive green like the back, and the under and upper tail coverts are black. The tail consists of 10 feathers, all of which are tipped with a broad band of buffy white.

The hoatzin harmonizes well with its environment, the dark upper color and the splashes and streaks of white and buff breaking up its body form into sunlight and shadow. When sitting quietly, either perching or on its nest, it is extremely difficult to detect, and its fear of hawks shows that this concealment may perhaps serve a useful purpose.

The most interesting thing about its coloration is the way the colors of the under parts are carried out in the wings. The pale buffy cream of the breast has spread, as it were, over the broad wrist edge of the wing, and the rich chestnut of the belly has infiltrated through the larger flight feathers. It is most difficult to account for this correlation of limb and body patterns—a condition found in many reptiles and insects—but it seems to emphasize the fact that some important environmental factor or cause must be concerned with this apparently directive evolution of just such colors being arranged in just such patterns on totally different portions of the body.

When the hoatzin is once alarmed, silhouetted against the sky, with wings and tail spread, and crest waving, no more conspicuous object can be imagined.

The total length of the hoatzin is about 23 inches, the wing 12½, the tail 12, tarsus 2, middle toe and claw 3.

The single specimen already mentioned which I collected on the Guarapiche differs from all the other hoatzins I have examined in

having no buff on the crest, this color being replaced by dark reddish chestnut; the buffy cream of the breast is darker, while the edges and shaft lines of the wing coverts, mantle, and scapulars are buff instead of white, and the lower parts instead of maroon are reddish buff. The bird is altogether unlike those from other parts of South America. It is fully adult.

Summing up the hoatzin as a whole, we have a bird small of body with small head, short, curved beak, long, waving crest, and long, slender neck. The body plumage is loose and disintegrated, the wings and tail large in comparison with the body, and of strong, well-knit feathers—all the more remarkable when we consider the weak flight, soon to be discussed.

The shortness and stoutness of the beak may safely be correlated with the toughness of its vegetable food. Its short feet rather belie their strength, as the bird seems to have little real power in them, and is forever balancing itself with wings and tail.

PARASITES.

The unpleasant odor which characterizes hoatzins seems to have no effect on their insect parasites, and the cheek bristles are often encrusted with masses of the eggs of several large species of Mallophaga.

No thorough work has been done on the external parasites of this bird, but I obtained three species of Mallophaga from the hoatzin shot on the Guarapiche River in northeastern Venezuela. Two of these insects are new species and I have published their descriptions in Zoologica, vol. 1, No. 4. I am indebted for their descriptions, and the following most interesting notes, to Dr. Vernon L. Kellogg, of Stanford University.

Concerning the Opisthocomus Mallophaga, Dr. Kellogg says:

The three species are:

(1) *Goniocotes curtus* Nitzsch.—Heretofore taken from *Opisthocomus* and no other host.

(2) *Lipeurus*, sp. nov.—In the group *clypeata sutura distincta*, which group has been found heretofore only on maritime birds.

(3) *Colpocephalum* sp. nov.—An extraordinarily spiny beast, not much like anything else in the genus.

I am disappointed in finding these two new species. I hoped to find known parasites that might, by their relationship with other parasites, characteristic of the pheasants or the rails or some other group of birds, be a clue to the indication of your curious bird's phyletic affinities.

The one known species of parasite, the *Goniocotes*, belongs to a group of Mallophaga best represented, and most characteristically, on the pheasants. But the *Lipeurus*, although a new species, belongs just as unmistakably with a group of Mallophaga characteristic of such birds as boobies, albatrosses, cormorants, frigate birds, pelicans, and such strictly maritime forms.

FIELD NOTES IN VENEZUELA.

The first view which Mrs. Beebe and I had of living hoatzins was 2 miles up the Rio Guarapiche, in southeastern Venezuela, where we found a flock of 8 on March 27, 1908. Farther up we discovered 3 smaller flocks and later in the day a large assemblage of 25 individuals. The natives know them by the name of *Guacharacas de Aqua* and are well acquainted with the musky odor which emanates from their bodies. Being considered totally unfit for food, they are never killed and as a result have become extremely unsuspicious.

The following notes were written in the field:

The moment our dugout comes into view the hoatzins announce their presence by hoarse, croaking cries; grating and rasping to the ear like an unoiled wheel. Then, as we approach, those nearest flop or crawl inward through the branches, making a tremendous racket. This utterance has been termed a "hissing screech" by some writers, and although a very poor description of the sound, no better one comes to mind unless it is a croaking hiss. Buffon (13) tells us "Its voice is very strong, and it is less a cry than a howl." Quelch (38) says "The cry of the hoatzin is usually heard when they are disturbed, and it is one of which is not easy to give an exact idea. It recalls slightly the shrill screech of the guinea bird (*Numida*), but it is made up of disjointed utterances, like the notes heigh and sheigh (ei as in sleigh), pronounced with a peculiarly sharp and shrill intonation, so as to be quite hisslike." The reckless way of thrashing through the undergrowth, and the apparent looseness of wing and tail and general carelessness of plumage bring to mind the crazy antics of anis, a fact not wholly uninteresting when we recall certain hints of cuculine structure in the hoatzin.

Except during the extreme heat of midday the hoatzins prefer conspicuous positions overhanging the water on mangroves or other trees, among the foliage of which they roost at night. They appear to be extremely sedentary, and day after day we could be sure of finding the birds in the same place. We located 9 flocks, ranging from a single pair to 42 birds in number, and these seemed never to move from their favorite trees except when driven back a few yards into the jungle by our intruding canoe.

In these same trees over the water we found remains of many nests in various stages of disintegration. As the number of the nests bore a fairly accurate relation to the pairs of birds, and as we saw these large, rough platforms of sticks at no other points, circumstantial evidence would indicate that the sedentary life of these hoatzins is seasonal, if not, indeed, annual. We were told that they nest in May and June in this locality.

After they flop and clamber a few yards away from the canoe they all quiet down, and with waving crests crane their necks at us in curiosity from their perches. Each time they utter their grating note they raise the tail and wings, spreading both widely.

We had no opportunity of observing the quadrupedal habits of the young hoatzins, but an interesting observation, first noted by Mrs. Beebe, was that this finger or handlike use of the wing is present in the adults as well. They never fly if they can help it, and even when they pass over firm ground seem never to descend to it. But their method of arboreal locomotion is to push and flop from branch to branch. When the foliage and hanging vines are very thick they use their wings, either together or alternately, to push aside the obstruction and to keep themselves from falling until a firm grip has been obtained with the toes. This habit is extremely wearing on the primary feathers, which become much frayed from friction against stems and branches.

I secured two specimens for the skin and the skeleton, respectively, and found them in an interestingly irregular molt. In one (Coll. No. 1138) the right third primary and the left fourth, seventh, and tenth are about half grown. In the tail, the next to the outer pair and the right central rectrices are in the same stage of growth, while blood feathers are scattered here and there over the body.

The second hoatzin examined (Coll. No. 1139) was in a still more disheveled condition of plumage. Both wings and tail were badly frayed and broken. Instead of the full number of 10 tail feathers only 5 were present, 1 of which was half grown. Three blood-filled sheaths just appearing above the surface of the skin represented the remainder. In the right wing the second, eighth, eighteenth, nineteenth, and twentieth were considerably less than half grown. The head, back, and thighs of this individual showed heavy molt, besides many growing feathers over the rest of the body.

The crops of these birds were distended with a finely comminuted mass of bright green vegetable matter, the leaves of the mangroves and some other river growths.

In one crop, scales and the remains of a small fish were also present, and as we once saw a hoatzin with dripping plumage, creeping from the water up a slanting mangrove root, it may be that the adult birds retain some of the natatory skill which characterizes the nestlings. This, however, is mere conjecture. The scales in this instance were those of the little four-eyed fish (*Anableps anableps*) so common about the muddy shores of the Caños.

FIELD NOTES IN BRITISH GUIANA.

On April 12, 1909, Mrs. Beebe and I reached a bungalow used as the headquarters of a rice plantation, some 20 miles up the Abary

River in British Guiana. Through the kindness of Mr. and Mrs. Lindley Vinton we obtained permission to remain here several days, with excellent opportunities of studying the hoatzins. Three days after our arrival Mrs. Beebe had the misfortune to break her arm, and we were compelled to leave at once, with only a few notes and photographs. These are, however, of sufficient interest to warrant publication.

The Abary River is at this point some 20 yards across, and winds through a great treeless savanna marsh in a general north and south direction. The east bank is for the most part clear of growth, except for the reeds and grasses of the savanna. Along the western bank is a dense shrubby or bushy line of vegetation, at times rising to a height of 20 or 30 feet or again appearing only 2 or 3 yards above the grass and reeds beyond.

The presence of this bushy vegetation on only one side of the river is probably due to the prevailing winds, which blow from the east. The bush grows altogether in the water and consists chiefly of a species of tall arum, or mucka-mucka as the natives call it, frequently bound together by a tangle of delicate vines. Here and there is a treelike growth, white barked with entire obtuse leaves. This narrow ribbon of aquatic growth is the home of the hoatzins, and from one year's end to another they may be found along the same reaches of the river. In general, their habits do not differ from those of the birds which we observed in Venezuela.

Throughout the heat of midday no sight or sound reveals the presence of the birds, but as the afternoon wears on a single raucous squawk may be heard in the distance, and we know that the hoatzins are astir. Directly in front of the bungalow, between it and the river, the brush has been cut away on either hand for a distance of about 60 yards. Every evening from 4.30 to 5.30 p. m. the hoatzins gather on the extreme northern end of this wide break in their line of thickets, until sometimes 25 or 30 birds are in sight at once. Some fly down to the low branches and begin to tear off pieces of the young tender shoots of the mucka-mucka. With much noise and flapping of wings several soon make their way to a single bare branch which projects over the cleared marsh.

The first bird makes many false starts, crouching and then losing heart, but the next on the branch, getting impatient, nudges him a bit, and at last he launches out into the air. With rather slow wing beats, but working apparently with all his power, he spans the wide expanse of clear bush, then the 10 feet of water, then 15 yards more of stumps, and with a final effort he clutches a branch—and his goal is reached. After several minutes of breathlessness he makes his way out of sight into the depths of the brush. A second hoatzin essays the feat, but fails ignominiously, and falls midway, coming

down all of a heap among the stumps. Here a rest is taken, and for 5 or 10 minutes the bird may feed quietly. Then a second flight carries it back to the starting point or on to the end of the open space.

Sometimes when the birds alight and clutch a twig they are so exhausted that they topple over and hang upside down for a moment.

Watching the hoatzins carefully with our stereo glasses for several evenings in succession, we came to know and distinguish individual birds. Two, one of which has a broken feather in the right wing, and the other a 2-inch short central tail feather, are excellent flyers, and, taking their flapping start from the high branch, never fail to make their goal, going the whole distance and alighting easily. All of the others have to rest, and one which is molting a feather in each wing can achieve only about 10 yards. This one fell one evening into the water at the second relay flight and half flopped half swam ashore.

One evening a hoatzin flew toward us and alighted near some hens on the ground, but took wing almost instantly back to his brushwood. A day or two before we came one of the birds had used a beam of the porch as a perch.

This general shifting occurs at both sunrise and sunset, and is apparently always as thorough and noisy as we found it the first evening of our stay. For months, we are told, it had been kept up as regularly as clockwork.

In the morning as the sun grows hotter the birds become more quiet, and finally disappear, not to be seen or heard again until afternoon. They spend the heat of the day sitting on their nests or perched on branches in the cooler, deeper recesses of their linear jungle.

The last view of them in the morning, as the heat becomes intense, or late in the evening, usually reveals them resting on the branches in pairs close together. On moonlight nights, however, they are active and noisy, and come into the open to feed.

The habit of crouching or squatting down on the perch is very common with the hoatzins, and it may be due to the weakness of the feet and toes. I am inclined, however, to consider it in connection with the general awkwardness in alighting and climbing, as a hint of the inadaptibility of the large feet to the small size of the twigs and branches among which it lives. Inexplicable though it may appear, the hoatzin, although evidently unchanged in many respects through long epochs, is far from being perfectly adapted to its present environment. It has a severe struggle for existence, and the least increase of any foe or the appearance of any new handicap would result in its speedy extinction.

FOOD.

The hoatzin is unquestionably a vegetarian, and the remains of the previously mentioned four-eyed fish in the crop of one of my Venezuelan specimens must have been evidence of an abnormal diet.

Examinations of the stomachs of individuals from various localities show that two or three species of marshy plants furnish almost the entire menu of this bird. One is the mucka-mucka or arum (*Montrichardia arborescens*), a tall plant of spindly growth, with large, tough, heart-shaped leaves, and a pineapplelike fruit. The leaves, flowers, and fruit are all eaten.

Hoatzins also feed on the *Drepanocarpus lunatus*, and, both in Guiana and Venezuela, devour the tough leaves of the white mangrove (*Arvicennia nitida*). Bates (3) includes the sour guava (*Psidium*) and "various wild fruits" in his list of its food.

NEST AND EGGS.

At the time of our arrival on the Abary the hoatzins had just begun to nest. They were utilizing old nests which, although apparently so flimsy in construction, yet are remarkably cohesive. The nests are almost indistinguishable from those of the "Chows" or Guiana green herons (*Butorides striata*), which were built in the same situations. The latter were usually placed low over the water, while the hoatzins were higher, from 5 to 12 feet above the surface of the marsh. The twigs were longer and more tightly laced in the hoatzins' nests, and while the herons' nests crumbled when lifted from the crotch, the others remained intact. The hoatzins placed their nests in a crotch of the white-barked trees, or more rarely supported by several branched mucka-mucka stems. Both sexes assist in the building, as we observed two birds collecting and weaving the twigs. Three sets of eggs which came under our observation numbered, respectively, 2, 3, and 4. From what information I could gather, 2 seems to be the usual number. There is no foundation for the assertion that these birds are polygamous.

There is little accurate data in regard to the date of nesting of hoatzins. It is possible that it differs in different places, and that no definite limits can be set to cover the species as a whole.

On the Orinoco, near Ciudad Bolivar, Cherrie (16) records that the nesting season extends from early in June until mid-September, thus including the height of the rainy season. Quelch (38) in British Guiana found the hoatzin nesting from December to July, and thinks it "very likely that it is continuous throughout the year."

In Venezuela the last of March the birds were not nesting, and those examined showed no signs of a recent breeding season. In mid-April in British Guiana the hoatzins were just beginning to nest.

The eggs are rather variable in shape. One which I have from the Orinoco is elliptical, while my Abary specimens are oval. The ground color is creamy white. The entire surface is marked with small, irregularly shaped dots and spots of reddish brown, inclining to be more abundant at the large end. The brown pigment deposited early in the oviduct is covered by a thin layer of lime and thereby given a lavender hue. The size averages 1.8 by 1.3 inches.

ENEMIES.

Hoatzins seem to be very free from enemies, although from year to year their numbers remain about the same. The waters beneath them are inhabited by otters, crocodiles, anacondas, and voracious fish, so that death lies that way. They seem also to fear some predatory bird, for whenever a harmless hawk skims over the branches on the lookout for lizards, the hoatzins always tumble pell-mell into the shelter of the thick foliage below.

PHOTOGRAPHING HOATZINS.

We found that the best time to approach and photograph the birds was during their siesta. As we paddle along the bank, they scramble from their perches or nests up to the bare branches overhead, calling hoarsely to one another. Pushing aside the dense growth of arums and vines, we work our canoe as far as possible into the heart of the brush to the foot of some good-sized marsh tree perhaps a foot in diameter. I step from the boat to the lowest limb, Mrs. Beebe hands me the big Graflex with the unwieldy but necessary 27-inch lens, and I begin my painful ascent. At first all is easy-going, but as I ascend I break off numerous dead twigs, and from the broken stub of each issues a horde of black stinging ants. These hasten my ascent and at last I make my way out on the swaying upper branches (pl. 5, fig. 1). From here I have a fairly clear view of the surrounding brush, and if I work rapidly I can secure three or four pictures before the hoatzins take flight and hide amid the foliage.

Of all my pictures, that of plate 3 is the prize. We came upon a flock of hoatzins late in the afternoon and were fortunate enough to get into a clear space and to photograph 11 on the same plate; the confused mass near the center of the picture containing four individuals. Plate 4, figure 1, shows the character of the country where we found the hoatzin on Abary Creek, with the line of dense growth on one side and the level savanna on the other.

A photographic study of an individual pair of birds is given in plate 5, figure 2, to plate 7. The action of these two birds is so typi-

cal of hoatzins that an account of them will apply to the species in general. I made these photographs from a boat, standing on the thwarts, while Mrs. Beebe guided it through the brush.

We flush the female from her nest, and she flies to a branch some 8 feet higher, the male then appearing from a tree beyond (pl. 5, fig. 2). We remain perfectly quiet, and the next photograph shows the female hoatzin, tail on, looking about, while the male, who has flown nearer, is watching us suspiciously (pl. 6, fig. 1).

Plate 6, figure 2, shows the male on another perch, still more alarmed, and a moment later he thrashes his way out of sight. Meanwhile the female has rediscovered us and crouches down (pl. 7, fig. 1), hoping to avoid observation, but as we push closer to the nest, she rises on her perch, spreads wings and tail to the widest (pl. 7, fig. 2), her scarlet eyes flashing, and, uttering a last despairing hiss, launches out for a few yards. At this moment, as may be seen in the same picture, a second pair of birds fly up from a nest in the next clump of undergrowth and raise their discordant notes in protest at our intrusion.

The assertion which I made last year that hoatzins use their primary feathers as fingers, in the same way that the chicks and partly grown young use their wing claws, has been received with some doubt, and I am glad to offer a photograph (pl. 7, fig. 2) as evidence. In the right wing of the hoatzin the thumb feathers are plainly visible, with their edges fretted away, while the first six primaries also show signs of severe wear, such as would be expected from the rough usage to which they are put.

Attention is called to the apparent immobility of the crest, which is as fully erect in the crouching hoatzin (pl. 7, fig. 1) as in the same bird a minute or two later, alert and about to fly (pl. 7, fig. 2).

Thus it was that we made the first photographs ever taken of these most interesting birds.

ODOR.

In regard to the odor given off by the flesh of hoatzins and its cause, there seem to be many conflicting statements. I quote some opinions:

> I never found the smell of these birds so bad as I had been led to believe; it reminds one of a rather strong cow shed. It has been found on cutting out the crop, as soon as the bird is dead, very little unpleasant odor remains. Loat (27).

> As is well known, the aroid shrub upon which the Canje pheasant feeds gives its flesh a strong and disagreeable odor. Sclater (41).

> The popular name (*Catingueira*) is derived from a certain penetrating odor. This disagreeable odor is transmitted and adheres with such efficacy that it is an excellent protection, not only against the attacks of carnivorous animals, but also against persecution by man. Goeldi (20).

Even by man they are seldom meddled with, except for scientific purposes, since a peculiar and unpleasant odor attaches to the flesh, especially after death, and which seems to be due to the penetration of the fluid and gaseous contents of the digestive tract. On this account they are not generally eaten, but a few cases have been reported to me in which they have been utilized for food. Quelch (38).

The flesh has an unpleasant odor of musk combined with wet hides—a smell called by the Brazilians catinga; it is therefore uneatable. Bates (3).

On our Venezuelan trip we heard a great deal and were warned again and again concerning the frightful odor which was supposed to characterize these birds. Some said they would have to be skinned under water! We found this wholly false. When skinning or dissecting one of these hoatzins one notices the faintest of musky odors, not at all unpleasant, and indeed perceptible only when the attention is directed to it. Our specimens were certainly most inoffensive in this respect, and the flesh of one which we cooked and ate, while it was tough, was as clean and appetizing as that of a curassow.

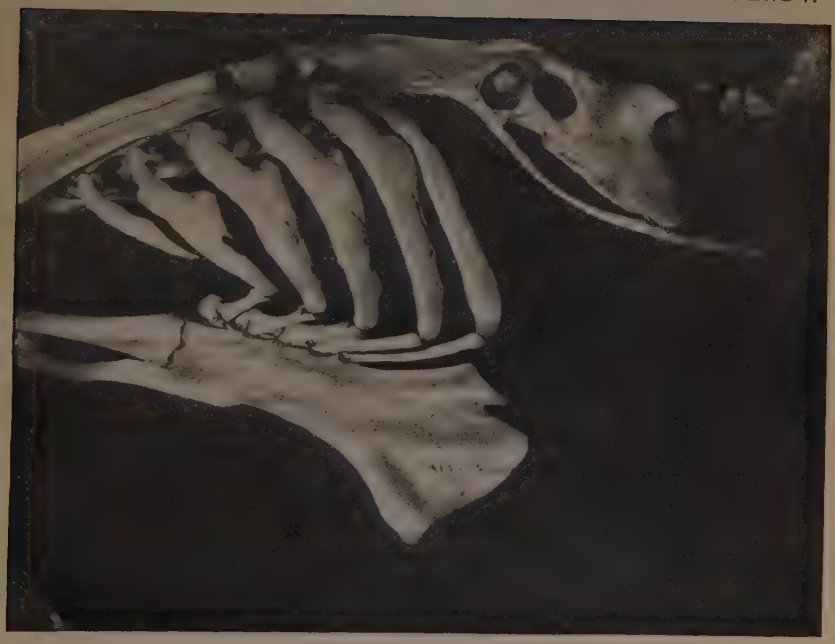
In British Guiana the above experience was repeated, although the "Stinking pheasant" was held in horror by the blacks. But, as before, we could detect nothing but a slightly musky odor. The odor is exceedingly persistent and is given off by skins which are several years old. Its cause is problematical and the direct connection with the crop is very doubtful. There is little doubt but that hoatzins differ greatly, either seasonably or individually, in regard to the intensity of this odor. Far be it from me, however, to emphasize any lack of it, for the very thread of existence of this most interesting bird hangs upon belief in this inedibility.

The Indians and other inhabitants of South America who depend upon wild game for food never waste powder, shot, or arrows on so-called sport. Until the "civilized" tourist penetrates to these regions, the hoatzins are safe. When he does arrive protection must be given to these interesting birds—a heritage to us from past ages. So helpless are they that, given a week's time and a shotgun, one man could completely exterminate them in the colony of British Guiana. Fortunately the game laws of that colony are comprehensive and wisely made, and the hoatzins are probably safe for many years to come.

BIBLIOGRAPHY.

(1) ALLEN, J. A. 1889. List of the Birds Collected in Bolivia. Bull. Am. Mus. Nat. His., Vol. 2, No. 2, p. 107.
(2) ASTLETT, H. A. 1909. MS. Letter, dated June 7th.
(3) BATES, H. W. 1892. The Naturalist on the River Amazons, pp. 60–61.
(4) BEDDARD, FRANK E. 1889. Contributions to the Anatomy of the Hoatzin. The Ibis. 6th Series. Vol. 1, pp. 283–293.
(5) BEEBE, C. WILLIAM. 1909. An Ornithological Reconnoissance of Northeastern Venezuela. Zoologica. Vol. 1, No. 3, p. 73.
(6) BEEBE, C. WILLIAM, and MARY BLAIR. 1909. Our Search for a Wilderness. Chapter 11. Henry Holt & Co., New York.

(7) BERLEPSCH, HANS GRAF VON. 1884. On Bird Skins from the Orinoco, Venezuela. The Ibis. 5th Series. Vol. 2, p. 440. (8) 1908. The Birds of Cayenne. Novitates Zoologicae. Vol. 15, p. 297.
(9) BERLEPSCH, HANS GRAF VON, AND HARTERT, ERNST. 1902. On the Birds of the Orinoco Region. Novitates Zoologicae. Vol. 9, p. 122.
(10) BINGHAM, HIRAM. 1909. The Journal of an Expedition Across Venezuela and Colombia, p. 61.
(11) BRISSON, M. J. 1760. Ornithologie. Vol. 1, p. 304.
(12) BROWN, C. BARRINGTON. 1876. Canoe and Camp Life in British Guiana, p. 257.
(13) BUFFON, G. L. L. DE. 1771. Historie Naturelle Oiseaux, Vol. 2, p. 385.
(14) BURMEISTER, HERMANN. 1856. Thiere Brasiliens, Vol. 3, pp. 342–3. (15) 1870. Journal für Ornithologie, p. 318.
(16) CHERRIE, GEORGE K. 1909. The Hoatzin. The Museum News, Vol. 4, pp. 50–53.
(17) EVANS, A. H. 1899. Cambridge Natural History, Birds, Vol. 9, pp. 241–242.
(18) GADOW, HANS. 1892. Crop and Sternum of Opisthocomus Cristatus. Proc. Royal Irish Acad. 3rd Series. Vol. 2, pp. 147–153.
(19) GARROD, A. H. 1879. Notes on Points in the Anatomy of the Hoatzin. Proc. Zool. Soc., Lon., pp. 109–114.
(20) GOELDI, EMIL A. 1894. As Aves do Brazil, pp. 442–445. (21) 1903. Ornithological Results of an Expedition up the Capim River. The Ibis. 8th Series. Vol. 3, p. 417.
(22) HERNANDEZ. 1651. Nova Plantarum, Animalium et Mineralium Mexicanorum Historia, p. 320.
(23) HORNADAY, W. T. 1876. Unpublished Journal.
(24) HUXLEY, T. H. 1868. The Affinities of Opisthocomus. Proc. Zool. Soc., Lon., pp. 304–311.
(25) IHERING, HERMANN VON. 1907. As Aves do Brazil, p. 26.
(26) LATHAM. 1783. Gen. Syn., Vol. 2, pt. 2, p. 741.
(27) LOAT, W. L. S. 1898. Field Notes on the Birds of British Guiana. The Ibis. 7th Series. Vol. 4, pp. 558–567.
(28) MÜLLER. 1776. S. N. Suppl., p. 125.
(29) NEWTON, ALFRED. 1893–6. Dictionary of Birds, p. 423.
(30) OGILVIE-GRANT, W. R. 1893. Catalogue of the Birds in the British Museum. Vol. 22, pp. 523–525. (31) 1905. Guide to the Birds in the British Museum, p. 56.
(32) PARKER, W. K. 1891. On the Morphology of a Reptilian Bird. Trans. Zool. Soc., Lon., pp. 43–85.
(33) PELZELN, AUGUST VON. 1871. Zur Ornithologie Brasiliens, p. 280.
(34) PENARD, P. AND A. 1908. De Vogels van Guyana, pp. 307–309.
(35) PERRIN, J. B. 1876. On the Myology of Opisthocomus Cristatus. Trans. Zool. Soc., Lon., Vol. 9, part 6, pp. 353–370.
(36) QUELCH, J. J. 1888. Notes on the Breeding of the Hoatzin. The Ibis. 5th Series. Vol. 6, p. 378. (37) 1888. A Collecting Trip on the Abary. Timehri, N. S., Vol. 2, part 2, p. 364. (38) 1890. On the Habits of the Hoatzin. The Ibis. 6th Series. Vol. 2, pp. 327–335.
(39) SCHOMBURGK, RICHARD. 1848. Reisen in British Guiana, Vol. 3, p. 712.
(40) SCLATER, P. L. 1857. Further Additions to the List of Birds Received in Collections from Bogota. Proc. Zool. Soc., Lon., pp. 15–20. (41) 1887. British Guiana and its Birds. Ibis. 5th Series. Vol. 5, p. 319.
(42) SCHLATER AND SALVIN. 1873. The Birds of Eastern Peru. Proc. Zool. Soc., Lon., p. 308.
(43) SHARPE, R. BOWDLER. 1891. A Review of Recent Attempts to Classify Birds, p. 70. (44) 1898. Wonders of the Bird World, p. 19. (45) 1899. A Handlist of the Genera and Species of Birds. Vol. 1, p. 93.
(46) STEJNEGER, L. 1885. Riverside Natural History, Vol. 4, Birds, p. 196.
(47) STEPHENS, J. F. 1819. Hoatzin Serpent-eater. Shaw's General Zoology, Vol. 11, pp.192–194.
(48) WALLACE, A. R. 1876. Geographical Distribution of Animals, Vol. 2, p. 345.



BREAST-BONE OF HOATZIN.

HALF-GROWN HOATZIN, SHOWING CLAWS ON THUMB AND FIRST FINGER.

FLOCK OF ELEVEN HOATZINS ON THE ABARY RIVER.

1. HAUNT OF THE HOATZIN, ABARY RIVER, BRITISH GUIANA.

2. NEST OF HOATZIN IN DENSE GROWTH OF MUCKA-MUCKA.

1. AUTHOR PHOTOGRAPHING HOATZINS.

2. FEMALE HOATZIN FLUSHED FROM HER NEST; MALE BIRD APPROACHING.

1. FEMALE HOATZIN IN THE SAME POSITION; MALE HAVING FLOWN NEARER.

2. MALE HOATZIN ALARMED AND ABOUT TO TAKE FLIGHT.

1. FEMALE HOATZIN CROUCHING TO AVOID OBSERVATION.

2. FEMALE HOATZIN TAKING FLIGHT WITH WINGS FULLY SPREAD; A SECOND PAIR OF BIRDS LEAVING THEIR NEST IN THE BACKGROUND.

MIGRATION OF THE PACIFIC PLOVER TO AND FROM THE HAWAIIAN ISLANDS.[1]

By Henry W. Henshaw.

Since primitive times the phenomenon of bird migration has excited peculiar interest, and although much of the mystery formerly attaching to it has been dispelled by the prosaic facts brought to light by modern investigations, it still presents enigmas to stimulate the imagination and invite study. How birds migrate is now beginning to be understood, and the present practice of tabulating dates of arrival and departure and collating the facts gathered by numerous observers in different parts of the country is likely ere long to give us the solution of many as yet unsolved problems. Why birds migrate is quite another question, likely to resist satisfactory solution for some time to come for, were there no other reason, from the very nature of the case we can have comparatively few facts to guide us, and speculation must largely take the place of deduction.

When we consider the number of miles traveled, the widely different character of the regions chosen for summer and winter abodes, and the perils necessarily attending the passage between them, the migration of no other of our birds appears so wonderful as that of the golden plover. In part the migration route of the eastern form of the golden plover (*Charadrius dominicus*) is well understood, and those interested in the subject are referred to a suggestive paper by Austin H. Clarke[2] on the probable method by which the bird is guided safely across the Atlantic from Nova Scotia to South America. In the present paper will be presented such facts in regard to the migration of the Pacific plover (*Charadrius dominicus fulvus*) as the author was able to gather during his stay in the Hawaiian Islands—from 1894 to 1904—together with certain deductions therefrom.

[1] Reprinted by permission, after author's revision, from The Auk, a quarterly journal of ornithology, Cambridge, Mass., vol. 27, No. 3, July, 1910.

[2] Auk, pp. 134–140, 1905.

Isolation of the Hawaiian Islands.—It may be premised that no other part of the earth's surface is so far distant from continental areas as the Hawaiian Archipelago. The islands are about 2,000 miles from the coast of California on the east; about the same distance from the Aleutians on the north and the Marquesas Group on the south; and not much farther from Japan, reckoning from the outermost of the chain of low islands and reefs which stretches from Hawaii some 1,700 miles toward the Asiatic coast. It is important to note, however, that, assuming the availability of these islands as stepping-stones for birds, there would still be an interval of more than 2,000 miles between the most northwestern of the chain and Japan. Hence, if we reject as untenable the theory of a sunken southern continent, of which the Hawaiian Archipelago is the northernmost and now the only visible remains, the original introduction into Hawaii of its mammals, birds, insects, and plants presented greater difficulties than were presented to the fauna and flora of any other part of the world.

So remote and isolated have these islands been since their formation, and so few and uncertain nature's carrying agencies—the birds, the winds, and the ocean currents—that after the islands were thrust up out of the sea ages must have elapsed before they received the parent stocks of the many and diverse forms of plant and animal life peculiar to them.

That the difficulties of stocking the archipelago with life, great as they must have been, were not insurmountable is proved by the fact that enough waifs found their way to the islands to clothe them with verdure and stock them with animal life. As a result of the competitive struggle which followed, upward of 900 species of plants, numerous insects, including many distinct genera, seven species of lizards, more than 50 species of birds, and at least two mammals, finally made good their foothold on the islands and flourished, some more, some less, according to their nature and adaptability.

Avifauna of the Hawaiian Islands.—Among other inhabitants of the islands are some 45 species of passerine birds, one hawk, an owl, a mud hen, a gallinule, a stilt, a duck, a goose, and a few others. All of these I pass by for the moment and come to certain migrants from North America which regularly journey between the islands and the continent, both spring and fall. Four of these migrate in great numbers, viz, golden plover, turnstone, wandering tatler, and bristle-thighed curlew; the shoveler duck and pintail also visit the islands in considerable numbers. In addition to these are perhaps a dozen other ducks and geese whose occurrence in the islands is more or less casual, and the same remark applies to a dozen or 15 wading birds. Altogether, including the regular migrants, the

casuals, and the accidentals, the visiting birds make quite a respectable winged army.

Islands accidentally discovered by present migrants.—It is not supposable that birds ever put to sea to seek unknown lands by a hitherto untraveled route. We know that millions of birds of many species are annually or semiannually driven out to sea by storms, especially species that migrate near the seacoast. Many, perhaps most, of these storm-driven waifs never see land again, but become wing weary and find watery graves. Some few, however, reach safe havens in oceanic islands, and in this way, no doubt, such islands have received their bird colonists.

That the golden plover, like the other migrants from the North American coast, discovered Hawaii accidentally is hardly open to doubt. I see no necessity for presupposing the existence of sunken continents or of ancient continental extensions to account for the presence on the islands of the plover and other North American birds, like the night heron, gallinule, and coot. The presence there of the weak-winged passerines is another matter, and it must be admitted that proof of the existence of an ancient continent, stretching from the islands southward toward Australia, would simplify a very difficult problem. So far, however, as our North American birds are concerned, it need be assumed only that long ago some thousands of Pacific plover and other species, when following the usual southward migration route along the Asiatic coast in fall, were accidentally driven to sea, and that a greater or less number were able to maintain themselves on the wing long enough to make a lucky landfall of the low islands to the northwest of Hawaii. The flight from Japan to the nearest island eastward would involve a flight about as prolonged as that from the Aleutian Archipelago to Hawaii, or some 2,000 miles. The chain of low islets once gained, it would be but a question of time for migrants, step by step, to reach the larger islands of Hawaii, 1,700 miles or so to the eastward. After wintering, a sufficient number may have essayed the flight back across the ocean to the Asiatic coast the following spring, and then northward to their Siberian breeding grounds with their Asiatic fellows. Having once discovered the islands and learned their suitability as winter quarters, they would no doubt return over the same route, and thus in time establish a regular fly line or migration route from the Asiatic mainland to the islands. Later, as the position of the islands became better known, the part-land, part-water route would naturally be exchanged for a shorter all-water route. It is possible, however, that the old Asiatic route has never been wholly abandoned and that it is still favored by a certain number of the island migrants; for plover, turnstones, curlew, and tatlers have been observed on Laysan, about 600 miles northwest of Hawaii, late in May. These

birds were probably about to migrate across the ocean, but it is, of course, impossible to tell whether they were headed directly for America or for America via Asia.

Absence of fog.—The original discovery of the Hawaiian Islands by birds was undoubtedly greatly facilitated by the fact that, although fog is common on the mountains at altitudes of 5,000 feet and upward, it never occurs at sea level; and as its absence favored the original avian discoverers, so it continues to favor annual migrants.

Date of discovery of the islands by American migrants.—As to the length of time the Pacific golden plover and its fellow migrants have been visiting the Hawaiian Islands, or when they first discovered the group, it were idle to speculate. Their arrival probably antedated by thousands of years that of the natives, which is supposed to date back only some 20 centuries. Certain of the bird colonists from America, like the owl, night heron, gallinule, and coot, have resided in the islands so short a time that they have changed very little from their American ancestry. Others, like the hawk, stilt, and goose, have changed more, and hence presumably have been residents of Hawaii a longer time. Changes of color, proportion, and size, however, be they great or small, can not be used as time measures, except in the vaguest way, since practically next to nothing is known of the length of time they require. We are perhaps justified in concluding that none of the above species have changed sufficiently to call for isolation from their American ancestors for periods to be reckoned by geologic intervals rather than by thousands of years.

Spring migration of plover.—The impulse to migrate in spring is by no means simultaneous among all the plover that winter in the islands or that winter on any one island, nor, apparently, is it the rule for large bodies of plover to migrate together. The plover and turnstones, probably often in mixed companies, begin to leave for the north early in April, and the migration continues till at least the latter part of May (probably even later), being dependent, apparently, on the state of preparedness or the inclination of individual birds.

When the time to migrate comes, small parties, from a dozen or even less, to flocks of 200 or more, strike boldly out to the northward, apparently without hesitancy or doubt of the result. Mr. Haswell, of Papaikou, which is on the coast about 15 miles north of Hilo, soon after daybreak during the early days of April, 1900, saw several flocks rise to a great height and, after widely circling about a few times as if to orient themselves, finally disappear in a northerly direction.

It is probable, however, that day migration is not the rule with plover and other shore birds. Apparently it is more usual for the flocks to feed by day and leave just before nightfall, as do many other birds in different parts of the world. Mr. R. C. L. Perkins states that several times he "witnessed these departures, always late in the afternoon or just before dark." He adds:

> When about to return to the north, the plover frequently assemble in very large flocks, and before setting out on their journey rise to an enormous height in the air, even beyond the range of sight. I have once seen two such flocks start from the same point, the one following the other after an hour's interval.—[Fauna Hawaiiensis, Vol. I, pt. iv, p. 449, 1903.]

It is interesting to note that plover are occasionally sighted from passing ships. Naturally they attract little attention and never are recorded in the ship's log. I found one ship captain, however, who remembered to have seen a flock of plover passing north in spring. The date was uncertain, but the ship was about midway between San Francisco and Hawaii, and the plover were steering a course which would carry them to the neighborhood of the Aleutians.

Where data are so scarce and difficult to obtain it is worth noting, as bearing on the season and course of the spring migration of island birds, that Townsend captured a Pacific plover, which boarded the *Albatross* May 19, 1890, when 600 miles south of Kadiak. This bird was probably an island migrant nearing the end of its long flight. Elliott, also, speaking of the turnstone, states that he "met with it at sea 700 miles from the nearest land, flying northwest toward the Aleutian Islands, my ship being 800 miles west of the Straits of Fuca."

Physical condition of spring migrants.—During the last two months of their stay in the islands both the migrating plover and turnstones get very fat, and it is probable that individuals that are not in good condition do not attempt the flight, or if they do, do not survive the attempt. Toward April most plover seem to be in full breeding plumage, and I feel sure that none of the birds assuming the breeding dress remain behind, unless sick or wounded. There is, however, a small contingent, both of plover and turnstones, that summer in the islands, and these appear to consist wholly of immature individuals, which, as a rule, are thin and not in good trim.

Speed of migrating plover.—The migration of plover over a wide ocean involves two factors: (1) Ability to go without food for the time necessarily consumed in the flight. (2) Ability to make the journey without resting and yet not overtax the physical powers. As stated above, apparently all the migrating birds in spring are in good order, and some of them, especially the males, are exceedingly fat. They are thus in condition to exert their utmost powers for a considerable period and to do without food. I know of no actual

tests of the speed of plover. From my own observations I believe that when not fatigued the plover can easily enough fly 50 to 75 miles an hour, but it is doubtful if such speed can be maintained for any great length of time. I am confident, however, that a speed of 40 miles an hour is well within the bird's powers. At this rate the flight from Hawaii to the Aleutians, a distance of about 2,000 miles, would consume a little more than two days; or, allowing a speed of 35 miles an hour, the time occupied would be two days, nine hours. At first thought it does not seem possible for plover to fly continuously for so many hours without rest and food; yet the above statement can not be far from the truth. If the birds fly faster, the journey requires less time but the expenditure of more vital force; if slower, they husband strength at the cost of time. In either event the result would be about the same. Of the extreme limit of the plover's endurance in continuous flight we know nothing; nor do we know what proportion of the birds that start across the ocean are successful in making the flight. That the effort is too much for many individuals is hardly to be doubted, especially for young of the year, which are comparatively weak and unpracticed of wing.

A leaf from the notebook of Dr. E. A. Mearns is of interest in this connection. On the 9th of October, when on a transport bound for San Francisco and one day out of Honolulu, Mearns noticed a lone plover, which joined company with the ship for nearly two days. On the 10th his notebook records that the bird was still circling around and above the ship, as if designing to come aboard. Sometimes it flew close alongside and whistled plaintively. Once it rose very high in air and flew out of sight, probably trying to sight land on which to rest, but it soon returned from its fruitless quest. At 5 p. m. on the 10th it seemed weak and tired, but was still flying feebly alongside, its call notes continually growing fainter with waning strength. It was lost sight of at dusk, and was never seen again, but its fate is only too certain.

It may seem remarkable that this tired wanderer apparently never alighted on the water to rest. However, I recall only one instance in which an unwounded plover has been known to alight on the water and again take wing.[1] In considering this question it must not be forgotten that neither by birth nor habits is the plover a swimmer. It is a true wader, and though, like all of its family, it can swim when compelled to and can even alight on smooth water and again take wing, it does so probably only in very exceptional instances, and perhaps never for the purpose of resting when in migration.

Could we assume that the particular individual noted by Mearns made a direct course from the Aleutians to the point where inter-

[1] Rothchild, Avifauna of Laysan, pt. 1, xiv, 1893.

cepted by the transport, the incident would be valuable as affording a tolerable idea of the limit of the endurance and wing power of a plover. The bird, however, may have lost its way and have taken a very indirect course to the point where it was first seen from the ship. Unaware of the proximity of the islands to which it was bound, and which it might have reached in a few hours more, it became confused, and made the fatal mistake of following the ship's course. Before it finally succumbed to fatigue, it followed the ship for about 500 miles. Thus at the least calculation it flew 2,500 miles before it succumbed to fatigue, and probably very much farther.

Time of arrival of migrants in Alaska.—As the migration of the plover (and also the turnstone) from the islands begins during April and continues till into May, and possibly even later, the birds should arrive in Alaska at corresponding dates, the flight probably consuming not much more than two days. As a matter of fact, however, the mainland breeding grounds of the plover in Alaska are snowbound till well into May, and Turner states that the Pacific plover does not arrive at St. Michael till about June 1, a statement corroborated by Nelson. Although there is no necessary precise correspondence between the breeding time of the Pacific plover in Siberia and in Alaska, it is interesting to note the statement of Seebohm that the plover arrives on the Yenesay River, Siberia, June 5; and, referring to water birds generally, he adds that "very few eggs are laid on the tundra before the last week of June." (Geog. Dist. of the Charadriidæ, 1888, p. 58.) Where the plover and turnstone, which leave Hawaii early in April, spend the interval till the melting snow bares the hillsides in Alaska and exposes the previous season's crop of Vaccinium and Empetrum berries, upon which the plover in spring chiefly feed, is left to conjecture. As the Aleutian chain is nearly 1,200 miles long, however, and as comparatively little is known of its birds in spring, it is possible that early migrating shore birds sojourn on them until advancing summer prepares the mainland for their occupancy. This conjecture is to some extent supported by the statement by Elliott that a few straggling plover land on the Pribilofs in April, or early in May, on their way north to breed, but never remain long.

Breeding range of the golden plover.—Without doubt the chief breeding ground of the Pacific plover is eastern Siberia, but a considerable number breed on the American coast of Bering Sea from the vicinity of Bristol Bay (where taken by McKay at Nushagak, June, 1881) to near Bering Straits. The plover breeding on Kotzebue Sound, north of the straits, is *dominicus* (Grinnell), as also is the one breeding at Point Barrow (Murdock). Apparently *fulvus* does not breed at all in the interior of Alaska, these regions being occupied solely by *dominicus*. It concerns us to note in passing that,

unless Palmén is mistaken in his identification, *dominicus*, not content with its wide habitat in the interior of Alaska, crosses the straits, and breeds on the Chukchi Peninsula.[1] Thus the summer ranges of the two forms actually inosculate, the Asiatic form crossing to America and the American form crossing into Asia—an apparent anomaly in the case of geographic forms.

Hawaiian plover breed in Alaska.—It is, of course, impossible to absolutely identify the Pacific plovers breeding on the coast of Alaska with the winter visitors to Hawaii, yet there are certain facts tending to show that they are the same. (1) It is to be noted that of the winter visitors to the Hawaiian Islands not one is an exclusively Asiatic species. (2) The form of the wandering tatler, which regularly migrates to and from the islands is not the Asiatic form *brevipes*, but the American form *minor*. (3) There is evidence that the bristle-thighed curlew, also a winter visitor to the islands, breeds in Alaska, while it is not known to breed in Asia. As the two last-named birds, which breed exclusively in America so far as known at present, regularly winter in the islands, it is a fair inference, in the lack of evidence to the contrary, that the plover and turnstone, as also the other waders which winter causually in the islands, as the sanderling, pectoral sandpiper, sharp-tailed sandpiper, jacksnipe, knot, and others, also come from Alaska and not from Asia.

Fall migration of plover.—For some reason or other plover appear to arrive in the Commander Islands in fall very late, according to Stejneger, not till after the 15th of September; the last ones were observed in 1883 on the 28th of October. The turnstone, on the other hand, touches the Commanders on its return trip much earlier, according to the same author, as early as the last part of July.

Arrival of plover in Hawaii in fall.—Passing now to Hawaii, a small number of plover and also turnstones return there as early as the middle or the latter part of August. By inference these are the birds which leave for the breeding grounds earliest in spring, and so are the first to complete their parental duties; or, the first arrivals in Hawaii may be individuals which made the journey to Alaska, but for some reason did not breed, or whose nests were broken up, or whose mates were killed, for the Arctic tundras have their bird tragedies, as have other lands. Just as the turnstones reach and leave the Pribilofs in small straggling flocks, so they and the plover arrive in Hawaii; and it appears further that in fall, as in spring, they get into good condition for the flight, and then leave in no regular order nor at any set time, but just as the impulse seizes them.

Between the dates of early departure from Hawaii in spring and of early arrivals in fall there is thus an interval of some four months

[1] Palmén, Vega-Exped. Vetensk. Iak-t., Vol. V, 1887, p. 342–348; also Stejneger, Auk, 1888, pp. 308–310.

or more, quite long enough to permit the pairs to attend to their parental duties, to get into condition for the return journey, and to make the trip. So far as my observations extend, all the first arrivals in Hawaii in fall, both plover and turnstone, are adults in breeding plumage. I may add that they are invariably in good flesh and that some are very fat. Later arrivals, however, no doubt young of the year, are comparatively poor in flesh and require considerable time to fatten.

How migrants find their way across the ocean.—It thus appears that thousands of birds, large and small, make a 2,000-mile flight from Alaska to Hawaii in fall and return in spring. To answer the question how they find their way across the trackless waste we must leave the realm of fact and enter that of speculation. Ocean migration routes have generally been plausibly accounted for on the theory that the present fly lines were established ages ago when the land connections were very different, and when, by means of continental extensions and islands now sunken, part land, part water routes were easily followed. As such changes as the raising or depressing of continents are very gradual and extend through long periods, succeeding generations of migrants are supposed to have scarcely noticed the difference, and, even after the old landmarks had disappeared, to have been able to follow the ancient routes through the power of transmitted habit.

This explanation, however, does not apply to the case of the Hawaiian migrants, since there is no reason to suppose that the isolation of the Hawaiian Islands in relation to continental areas was ever less complete than now; and, although a theory has been advanced that the archipelago is the northern apex of a former southern continent, it finds little support from biologic, botanic, or hydrographic investigations. Moreover, such a continent extending southward toward Australia would have been of no assistance to birds migrating from America, though its former existence, could it be proven, would render easy the explanation of the derivation of the Australian elements of the Hawaiian fauna and flora. The presence of two shoals, situated, roughly speaking, midway between San Francisco and Hawaii, has suggested the former existence here of large islands, now sunken. If such islands really existed, which is doubtful, they unquestionably would have aided the passage of American birds and plants to the Hawaiian Islands.

In his interesting article on "The migration of certain shore birds," quoted above, Mr. Clark argues that prevailing winds, especially the steady trades, offer a reasonable explanation of the way certain birds are or may be guided in migrating. Such an explanation seems to apply peculiarly to the case of the American golden plover, which, as is well known, abandons the North American Con-

tinent at Labrador and Nova Scotia, and under ordinary circumstances makes no landfall till it strikes the Guiana coast, a distance of about 2,000 miles. It is perhaps more remarkable that instead of returning in spring to its breeding grounds by the same route it takes in fall to its winter quarters, it follows an all land route and traverses the length of two continents, thus furnishing the most extraordinary migration route of any existing bird, as pointed out by Prof. Cooke.

An attempt to apply to the case of the Pacific plover wintering in Hawaii the same principles so well worked out for the Atlantic coast form is not so successful. About September the wind that prevails in the north Pacific immediately south of the Aleutians is from the northwest. It is generally believed that migrating birds prefer to fly on a beam wind. By heading southwest birds migrating to Hawaii might have the northwest wind abeam till about the neighborhood of latitude 30°, where they would be almost sure to pick up the northeast trades. By then changing their course to southeast they would be enabled to fly with wind abeam till they sighted the islands. That they follow such a course in fall and steer their way by either the northwest wind or the northeast trades there is not a particle of evidence that I can bring forward, nor do I know any facts to justify a statement that they do or do not utilize the winds as guides either in fall or in spring.

The results of recent experiments by Prof. John B. Watson with sooty and noddy terns along our south Atlantic coast go far to prove the contention long maintained by many that birds actually possess a sense of direction tantamount to a sixth sense. If we grant this, as we may ultimately be compelled to do, the ability of birds to find their way both by land and sea is explained without further trouble and quite independently of landmarks of any kind or of the winds. The possession of such a useful sense will explain many difficult problems of migration, and among others the apparent confidence with which migrants boldly launch out from Hawaii for a 2,000-mile flight across the Pacific, without the aid of any compass apparent to human intelligence.

Danger of oceanic migration.—Of the fall migration of the golden plover on the Atlantic it may be remarked that, while the birds have no landmarks to steer by after leaving the northeast coast, they are yet within comparatively easy flight of the mainland, and in event of an unfavorable northeastern wind they can, and in fact often do, take refuge on the New England coast; and farther on, in bad weather or in case of unpropitious winds, they alight for rest and food in the West Indies.

The Pacific plover traverses a much more hazardous route, since, when once clear of the Aleutian Islands, it not only leaves all land-

marks behind, but also all ports of refuge. The Hawaiian Archipelago, with the chain of low islands and sand spits to the northwest, afford a reasonable chance for a successful landfall, since unitedly they stretch away in a very thin line for some 2,200 miles. Moreover, the islands are close enough together so that migrants high in air would not be likely to miss them by passing between. Flocks that chance to get to the eastward of Hawaii, however, are probably doomed, since they would have to fly another 1,000 miles or so before finding islets on which to rest. The Marquesas Group, the first islands of size to the south of Hawaii, is about 2,000 miles away, or about 4,000 miles from the Aleutians, and it is more than doubtful if even the strong-winged plover could fly 4,000 miles without rest and food and survive the trip. That many of the migrating shore birds actually perish at sea admits of no doubt.

In this connection it is of interest to note that in a few instances in which island migrants have been sighted when near their journey's end, going or coming, they exhibited fatigue and evinced a strong desire to board passing vessels. The incident noted by Dr. Mearns has been cited. Other instances were reported to me by the captains of two island-bound barks, who sighted several small flocks of plover during the last days of September, 1900, when from 200 to 400 miles off Hilo. These birds appeared much fatigued and exhibited a strong desire to board the ships, especially when their calls were imitated.

E. W. Nelson, however, while on the *Corwin*, October, 1881, saw a small party of plover about midway between the Alaska Peninsula and the Hawaiian Islands. These birds were headed directly for the islands, and they flew swiftly on their course, showing no signs either of uncertainty or of fatigue. Other similar cases might be cited.

Molts of the Pacific golden plover.—It is of interest to note that in fall this plover migrates before it molts; in spring it molts before it migrates. The first birds to reach the archipelago in August are, as stated, adults, and while they are practically in full breeding dress, they begin to molt into the winter dress almost at once. The molting season for the species is long, and many individuals, doubtless birds of the year, may be found the last of December still molting into the fall and winter dress. By the middle of February numerous individuals are already beginning to molt a second time and to assume the distinctive nuptial plumage, which in the case of these early birds is practically completed during the month of March, though individuals continue to molt far into April, and some no doubt complete the final stages in Alaska.[1] Doubtless the individuals to molt first in spring are the adults which arrive first and finish the fall molt first; and doubtless, too, these are the birds first to leave Hawaii for their

[1] I have several specimens taken in March and April, which were kindly sent me by my friends Mr. Henry Patten and Mr. W. B. Newell, of Hilo. These are in spring plumage, but show unmistakable signs of molting.

breeding grounds in Alaska. So protracted is the molt of the species that it is probably true that during the stay of this plover in Hawaii—from middle August till May—there is not a month when some individuals are not molting.

There is no reason for believing that the plover summering in the islands, which, as before stated, are chiefly if not wholly immature birds, participate in the spring molt. At all events, all the Hawaiian summer plover and turnstones I have seen were, without exception, in the winter garb.

Why the plover migrates.—We have thus seen that what at first might appear a physical impossibility—the 2,000-mile flight of small birds across an ocean highway without a single landmark and with only the friendly winds to guide them, if indeed they utilize these as guides—is not only possible, but the feat is accomplished annually by many thousands of individuals, and apparently with no stops for rest and food. The wonder of it is but increased when we realize that these annual flights are undertaken solely for the purpose of making a sojourn of a few brief weeks in Alaska to nest and rear their young. The hazards of such journeys are very great—much greater than any land migration, however prolonged—and there is no doubt that of the thousands daring the perils of the trip from Alaska many are lost, either by missing the islands altogether or by being caught in storms, or by reason of insufficient strength and wing power. The flight from the islands to Alaska, though not without danger, is less hazardous than the southern flight, both because a much greater proportion of the migrants are mature and experienced and because, in case they lose their way, they have two continents as marks to hit.

The motive for the fall migration of the plover, like that of the other waders breeding in the far North, is easily understood. Whatever may have been the case in the distant past, to-day the waders have no alternative. They must migrate from the Arctic in the fall or starve. The only choice offered is as to the selection of winter quarters. Thus compelled to migrate, it appears that a certain number of plover and of several other shore-birds find the Hawaiian Islands a winter resort so attractive that to reach them they brave the perils of migration across a wide and stormy ocean. Why, then, do they not permanently colonize the islands? If adapted to the bird's needs for nine months of the year, why not for the other three?

It can not be said of the spring migration of these Hawaiian migrants as of the fall, that the birds have no alternative. On the contrary the choice is open, and they would seem to have every incentive to remain, with no very apparent motive to migrate. The chief cause compelling winter visitors to the Tropics to leave and to seek northern regions in which to breed has been supposed to be the overcrowding of the Tropics in spring and the resulting lack of room and

of food. No such conditions appear to confront the winter sojourners of Hawaii. During its stay in the islands the plover, as also the turnstone, feeds chiefly in the upland pastures and clearings, up to 6,000 or 7,000 feet, and on newly-plowed cane land. Both the sugar planter and the stock raiser have much to thank the plover for, since, while the birds feed on small seeds to some extent, they live chiefly on insects, and according to Perkins, on insects of much economic importance, since they depend largely on the caterpillars of two of the most widely spread and destructive of the island "cut worms." These insects are most abundant when the grass on the island pastures is green and luxuriant, and this usually is in winter when rains are most copious. That the supply of food in winter and spring is ample is sufficiently attested by the fact that the birds get into such excellent condition. Even if it be assumed that the supply of food in summer is less than in spring, and hence inadequate for the needs of the thousands that winter here, together with their young, still there is enough to sustain very many more than the comparatively small number of nonbreeders that summer here.

From the standpoint of the food supply it is even more difficult to explain why the tattler and the curlew leave the islands in spring, since these birds feed almost wholly alongshore, where there can be no appreciable difference in the quantity of food summer and winter.

The question why the island plover migrate is all the more difficult to answer when we remember that the islands have been permanently colonized by certain other American birds, such as the Hawaiian stilt among the Limicolæ, the night heron of the Herodiones, the Hawaiian mud hen and gallinule of the Paludicolæ, the Hawaiian goose, the short-eared owl, and the island buteo. These birds came to the islands as waifs, as did the plover. Finding room, shelter, and food abundant, they wisely elected to roam no more, but to become permanent residents, and to forswear for all time the perilous and unnecessary habit of migration. Since they successfully resisted the impulse to return to their former summer homes to nest, then why not the other species? As stated above, the failure of the plover and turnstone to become permanent colonists is not because they are crowded out by other species. In fall the migrants from Alaska find the inviting island pastures unoccupied, and as they find them in fall, so they leave them in spring.

I can suggest no very convincing answer to the question, but I may note the significant fact that the present suitability of the islands as a breeding ground for the plover and turnstones is very recent as compared with the birds' acquaintance with them. The cleared strip around each island now planted chiefly to cane, which may be roughly stated to be 3 miles wide, and the extensive clearings above this strip which serve for pasture for cattle, are less than 100 years old,

most of them less than 50. Prior to their discovery by Europeans all the islands were heavily forested, nearly or quite to the shore. Possibly then the plover and other migrants have been slower to realize the situation than the other species, and do not even yet appreciate the advantages offered by continuous island life.

It may be said, too, that the spring migration of the plover and turnstone is so intimately interwoven with the function of reproduction that we are quite safe in assuming that, were it not for the desire to nest, the birds would never migrate. Those, in fact, which are not stirred by the impulse to nest, either because too immature or too old, do not migrate; and the intimate connection between migration and reproduction appears further from the fact that all the individuals that migrate don the nuptial dress before they start, a sufficient declaration of their purpose in undertaking the trip; while those that remain retain the dull winter plumage.

It appears to be true of all birds that, having once reached their winter quarters, be they near or far from the summer home, no migrating species attempts to return to its summer haunts till stimulated thereto by the profound physiological change consequent upon reproductive activity. This impulse is not primarily due to change of season or to change of temperature, but is periodic and physiological. When once felt, every instinct seems to impel birds to take the shortest route to the spot where they first saw the light or where they have reared young. This has often been called the home instinct. In the case of many species the phrase is not very happily chosen, though I myself have used it, since that locality is more properly to be called a bird's home where it spends the greater part of its life, rather than where it spends a few brief weeks annually. Nevertheless the power of habit transmitted through thousands of years is very great, and it is probably this influence associated with the reproductive instinct which so far has prevailed over other considerations and caused the plover to migrate from Hawaii in spring.

If the Charadriidine birds, the plovers, sandpipers, and curlews, originated in the Arctic, as Seebohm and others believe, and were forced by the exigencies of the ice age to become wanderers over the face of the earth, then indeed the spring migration of the waders from their distant winter resorts is more fitly termed a return home, and the instinct prompting the flight the homing instinct. Originally forced by the ice invasion to abandon their then Arctic paradise and seek shelter and food in distant parts, as the ice receded they gradually formed fly lines to and from their summer and winter homes till the habit formed during thousands of years became so fixed as to absolutely dominate many species. That it did not dominate all of the original migrants, however, appears from the fact that permanent colonies settled here and there even in tropical regions, showing that

under certain circumstances the habit of migration can be and is overcome. Of the island plover all we can say is that, so far as we can see, its spring migration to its Arctic breeding grounds is not necessary, except in so far as made so by the tyranny of habit.

This explanation has at least the advantage that it explains nothing, and hence leaves the problem open. It simply shifts slightly the point of view. We perceive that the island attractions have proved sufficiently strong to make permanent residents of certain species which have strayed to the archipelago. In the case of other strays, like the island plover and the turnstone, either the island attractions are not so strong or the birds' love for their original habitat is stronger, and they continue to migrate, though with much danger and at a great cost in lives.

Before leaving this subject I must add that several independent observers have reported finding a few young plover and turnstones in summer on the coast of Kau, island of Hawaii, and at one time I thought it possible that a few curlews also remained to breed; but in the case of none of these species was I able to fully satisfy myself that the birds reported were nestlings. It is, however, not impossible that occasionally a disabled female plover, tattler, turnstone, or curlew secures a mate and nests in Hawaii. Indeed, it seems highly probable that it is in this accidental sort of way that new avian colonies are occasionally planted. Such, indeed, may be the explanation of the resident colonies of American species like the coot, gallinule, and others above referred to. Possibly, too, young birds of the year remaining for the summer occasionally feel the breeding impulse after their comrades have left for the north, and so breed and found permanent colonies.

THE PLUMAGES OF THE OSTRICH.[1]

[With 8 plates.]

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By the plumage of the ostrich is understood the entire covering of feathers on the bird at any one time.[2] This is not the same at all periods, for the bird varies greatly in appearance between its chick and adult condition, dependent upon differences in the form, color, and other characters of its feathers. Visitors to zoological gardens in other countries, accustomed to seeing only the adult ostrich, would scarcely recognize the same bird in its earlier garb.

Four well-marked plumages can be distinguished in the ostrich, namely, the natal, the chick, the juvenal, and the adult. These represent four distinct kinds of feather which each feather socket on the bird can produce; but, as regards the bird as a whole, the passage from one stage to another is gradual, as there is no well-defined molting period involving a complete simultaneous change of feathers. Until the adult plumage is reached there is an intermingling or overlapping of the feathers belonging to different plumage stages, the older feathers being distinguished by their worn and faded appearance as contrasted with a freshness and perfection in the newer. Many birds, especially in colder regions, vary the character of their plumage between summer and winter, but the slight seasonal changes of South Africa have scarcely any influence on the feathers of the ostrich, and in the adult there is little or no difference in appearance between summer and winter and a well-defined molting period has not been established. The change from one plumage to the other is dependent upon age and nutrition rather than upon climatic considerations.

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[1] Reprinted by permission, with corrections by the author, from the Agricultural Journal of the Union of South Africa. Pretoria. Government Printing and Stationery Office. Vol. 1, No. 1, February, 1911. This article is in continuation of a series contributed by Dr. Duerden from time to time to the Cape Agricultural Journal.

[2] Among farmers the term plumage is sometimes restricted so as to refer only to the white wing quills. Thus, by an ostrich in "full plumage" is understood one in which the wing plumes are fully developed; when these have been clipped and the quills only remain a bird is said to be "in quills." Throughout this paper, however, plumage will refer to the covering of feathers as a whole.

THE NATAL OR BIRTH PLUMAGE.

Like the young of many other birds, the ostrich chick at hatching is already provided with feathers in the form of down. This is the natal or birth plumage, and consists of only down feathers,[1] which are very different from the feathers which will clothe the bird later. Some of these down feathers, taken from the back, sides, and under surface, are shown in the illustration. (Pl. 1, fig. 1.)

Though differing somewhat in size, the down feathers are of the same character all over the body and wings, a contrast to the various kinds of feathers which the bird produces later. They consist of small tufts of plumules, differing in length, and all starting from about the same level, there being no shaft or stem, as in the later feathers.[2] ach tuft consists of from 10 to 20 or more plumules, of which at least 4 are much longer than the others, being about 2½ inches in length in the side feathers but only about half as long on the back. A plumule is made up of a central axis or barb with small delicate barbules on each side. Toward their free end the larger plumules are without barbules, and on the down feathers of the back are prolonged into a rather coarse, flat, curled, strap-like portion, but on the feathers of the side and below they are narrower and more hair like. The flat naked parts of the barbs give a bristly hedgehog-like appearance to the young chick, and stand out conspicuously against the rest of the plumage. (Pl. 1, fig. 2.) Most of the remaining plumules have barbules all along their length and vary in size from an inch and a half to half an inch, while two or three are shorter. These soft delicate plumules give the downy character to the under part of the plumage of the young chick, though this is somewhat obscured toward the surface by the bristle-like character of the barbs of the long plumules. (Pl. 1, fig. 2.)

Even at the time of hatching it is possible to distinguish in the natal down great differences in the feather-producing capacity of various strains of birds. The down feathers in some strains are almost double the size of the feathers in other strains, while others again are denser and more glossy.

At all ages the neck and head of the ostrich are, as regards their plumage, sharply distinguished from the rest of the body. These parts are sometimes described as naked, but as a matter of fact they are thickly covered by feathers which are much smaller than those

[1] Down feathers are sometimes termed "plumules," but in ostrich feather terminology it is best to use plumule for each barb and the barbules attached to its sides. Thus each constituent of a down feather will be a plumule, as well as each separate part of the flue arising from the shaft in the adult plume.

[2] It has lately been shown that both the shaft and quill are absent from the first down feathers of birds, the barbs of the down feather passing without interruption into the new feather below. In the large down feathers of the ostrich, however, there is fully half an inch of quill.

on the body and wings, and have one or more of the plumules prolonged in a hair-like fashion. These hair-like feathers become bristly on the head, and form a special tuft around the ear openings, and also serve as eyelashes to the eyelids. The head and neck feathers of the chick are tufts of plumules like those on the body, only much smaller. Examples of the same feathers as they occur in the adult are shown in plate 8, figure 1, and are seen to have advanced very little beyond ordinary down. They do not overlap one another like the feathers on the body and wings.

The neck and head feathers vary in color in the chick, and on the neck the colors are so arranged as to give rise to from five to nine longitudinal dark bands, which are either continuous throughout the long neck or interrupted. Usually the dorsal three or five bands are continuous, while the rest are broken and somewhat ill defined. They are shown on the chicks in plate 1. On the head the dark feathers are arranged so as to produce a V-shaped pattern, the angle of the V pointing toward the beak. The sides of the V are either continuous or interrupted, this, according to some, denoting a sexual difference. The general color effect of the upper part of the head is a rich brown, shading off down the neck. On some chicks a small naked patch occurs on the back of the head and disappears later.

The down feathers of the back and sides of the body also vary in color from light to dark brown or nearly black, and, being intermingled, give a characteristic mottled appearance to the chick, as shown in plate 1, figure 2; the feathers on the under surface and in front are much paler in color, either yellow or white. But newly hatched chicks vary much in the general light or dark brown appearance of the natal plumage as a whole, dependent upon the relative number of the light and dark feathers. In some down feathers, light and dark plumules are intermingled, but usually a feather is either one shade or the other.

Both natal and chick feathers are found covering the outer surface of most of the upper region of the leg, but as the birds become older they largely disappear from this part, leaving the legs altogether naked (pl. 3, fig. 1); impressions of the sockets, however, remain for a long time.

The natal feathers are not molted in the ordinary manner of later feathers. A week or two after birth they begin to be pushed out of the feather sockets by the chick feathers growing below, the first to appear being those along the sides of the hinder part of the body. The down remains continuous with the tip of the new feather, and there persists until broken or worn off. On the tip of the wing quills the natal feathers remain for six months or more; that is, until the feathers (spadonas) are clipped or the tips worn away (pl. 2, fig. 4).

THE CHICK PLUMAGE.

The chick plumage is that which appears soon after the chick is hatched, and is completed at the age of about 8 months; that is, when the wing quills are fully ripe, these being the last to complete their growth. The feathers of this plumage are formed of the ordinary quill and plume, the flue of the latter being equally developed on each side of the shaft or stem. The chick feathers are distinguished from the later feathers by bearing at their tip the natal down feathers, due to the fact that the growth from the birth to the chick feather is continuous;[1] they also taper toward their free end. The feathers, surrounded by their sheath, begin to make their appearance when the chick is a week or two old, but not all at the same time, the earliest to push out being those over the sides of the hinder part of the body. The flue begins to expand when the chicks are between 3 and 4 weeks old.

The chick plumage lasts for a varied period, dependent partly upon the nutritive condition and partly upon the strain of the bird; some of the feathers remain on the bird for a year or more, while others are molted before the bird is 6 months old, when there results an intermingling of the chick and juvenal plumages.

The distinguishing feature of the chick plumage, as of the early plumage of many other birds, is its mottled character, agreeing in this respect with the natal plumage. In the chick, however, the mottling is not due to an intermingling of light and dark feathers, but to the fact that the upper part of each feather is light brown, while the lower part is of a dark gray color (pl. 2, fig. 1). The combination of light brown and dark gray colors gives a peculiar mottled or variegated color to the chicks for the greater part of the first year, but is more pronounced during the first six months while the feathers are young and fresh. Chicks from different parents vary much in the proportion of light brown and dark colors on the individual feathers, and hence in the general light or dark mottled effect of the plumage as a whole. The dark bands on the neck and head are nearly as pronounced as in the natal plumage.

The various kinds of feathers—body feathers, coverts, and wing and tail quills—now begin to show for the first time those differences which are such a marked feature of the adult. The wing quills

[1] It has recently been shown that in many birds the barbs of the new feather are directly continuous with the barbs of the down feather, no real break occurring between the two. For this reason some writers consider that the down feathers do not represent a distinct plumage, but are to be looked upon as the modified tip of the first true feather (the definitive feather). In the ostrich, however, there is a definite though weak quill, which makes a distinct break between the barbs of the down feather and those of the chick feather. Moreover, the quill of later feathers naturally molted is also continuous with the tip of the new feather, breaking off from it more readily than do the natal feathers on account of its greater weight.

(remiges) are from 1 to 2 feet in length when full grown, and, like the later wing quills, vary much in length, breadth, and other characters according to the strain. Like the rest of the chick feathers they never form the full rounded tip characteristic of the later wing quills, but taper considerably, hence their technical name of spadona, derived from the Italian spadone, the name for a long, heavy sword (pl. 2, fig. 2). The flue is somewhat narrow and thin compared with that of the later wing quills, and light brown above and white or gray below, the white being the more valuable. As the spadonas attain their full length they seem disproportionately large for a chick of 5 or 6 months, and when the wings are at rest the feathers of opposite sides may cross over one another under the body and behind the legs. From their nearness to the ground, the tips are more or less worn away as the plumes become fully grown.

The rectrices, or tail quills, are white below, gray above, and tipped with the usual brown, varying much in the proportions of the different tints. They are much shorter than the wing quills, and, like them, taper toward their free end.

The body feathers of the back and sides vary somewhat in length from different parts of the chick, and also in different strains of birds, but they all narrow toward their free end. The wing coverts and body feathers are of much the same shape, narrowing considerably toward the tip. The lower part of each is a light or dark gray color, while the upper part is light brown; the boundary between the two colors is irregular, and the proportion of the two colors on each feather also varies considerably. The chick feathers on the under part of the body are white or gray, and do not overlap in the same way as the upper feathers.

The wing quills or spadonas of the chick are practically the only feathers of any commercial importance at this stage, the wing coverts and tails having but little value. The spadonas complete their growth, as regards the whole of the plume and an inch or so of the quill, by the time the chicks are from 6 to 7 months old, and are then clipped for sale. The quill is, however, allowed to remain in the socket in order to complete its development. This requires about two months longer, so that the feather has not actually finished its growth and ripened before the chick is 8 or 8½ months old, by which time all the other feathers have ripened and many have been replaced by the feathers of the next plumage. As the feather ripens, the red blood in the central medulla or pith can be seen to recede slowly down the quill, which then becomes white and dry, filled with air, and hollow except for the presence of the horny feather cones which successively cut off the medulla. By the end of two months from clipping, the quills are practically ripe; that is, the blood has left the medulla and the whole quill has hardened and is narrowed

toward its extremity. It may then be extracted without injury to the bird. The plumes are clipped before the lower part of the quill is ripened, otherwise their tips would be much worn, and the feather as a whole greatly depreciated in value; this applies also to all the later feather crops. As the severance takes place through the upper ripened part, above the blood in the pith, there is no hemorrhage, which should be avoided for the sake of the later feather.

As regards the feathers of the chick plumage there is no reliable sexual difference in the ostrich, nothing to indicate which are cocks or hens, a matter often of much importance to the farmer. Usually, however, the spadonas from cock chicks are lighter than those from the hens. To determine the sex with certainty, however, other characters are available at this time.

The wing plumes being clipped at about 6 months, the tail quills and two rows of wing coverts are allowed to ripen, and are plucked at from 7 to 8 months; being of little value they are rarely clipped. All the other feathers of the chick plumage are allowed to follow the natural method of molting. The process is carried out at very different times in different parts of the bird and will be described in connection with the juvenal plumage.

From 5 to 6 months onward the chick plumage as a whole begins to lose its primary characteristics. Many of the body feathers are early pushed out by those of the juvenal plumage, and, as the latter are larger and uniformly steel gray, they show conspicuously among the mottled chick plumes. The chick feathers drop out first in the hip region by the time the chick is 5 months old, that is, before some of the other feathers of the plumage are fully grown. The chick feathers which are not replaced begin to lose their freshness of color from about 6 months onward, the lighter brown at the end of the feathers especially disappearing. In the wear and tear the tips are generally worn away, and the adhering natal feather is broken off.

The general color effect of the chick ostrich, in both the natal and chick stages (pl. 1, fig. 2, pl. 2, fig. 1), would appear to have a protective significance, the light and dark mottlings closely resembling the dry veld or grass on which the chicks usually crouch in nature. When at all alarmed, chicks suddenly scatter and then drop flat on the ground, with the neck and head extended, exhibiting death feigning to a greater or less degree, and in this condition all farmers have noted the difficulty in recognizing the chicks on account of the close resemblance which they bear to their surroundings.

THE JUVENAL PLUMAGE.

The third or juvenal plumage represents an intermediate stage betwen the chick and the adult plumage. It does not, however, follow immediately upon the second or chick plumage, as molting is

never uniform over all the body. The body feathers of the chick are pushed out gradually, one at a time, not simultaneously, from 4 or 5 months onward, and are replaced by larger feathers of an altogether different type. Instead of being mottled, the new feathers are of a uniformly dark gray or slate color, often tinged with white for a time at the extreme tip, which is no longer tapering but rounded (pl. 3, fig. 1). The juvenal feathers first appear along the sides of the hinder part of the body, a number coming out about the same time. Often the chick feather will remain attached to the tip of the new feather, hanging loosely, and only breaking off after the juvenal feather has protruded for some distance. After a number have grown out at the sides others begin to appear along the back, and then odd ones push out over the body generally. Some chick feathers may, however, remain in their sockets until the birds are 12 months or more old, those around the base of the neck being the last to drop out. The rapidity of the change is partly determined by the nutritive condition of the bird and partly by the strain.

The chick, as a whole, begins to lose its mottled appearance from 6 to 9 months onward. This is partly due to the replacement of the lighter tipped chick feathers by juvenals of a uniform hue and partly to the fading and wearing away of the light brown tip of the old ones remaining. By the time the chicks are a year old, nearly all the body feathers show the slate or drab color of the juvenal plumage, those of the cocks being somewhat darker than those of the hens. All the feathers of the plumage, however, are not fully ripe until the birds are about 16 months old, as usual the last to ripen being the wing quills. In the wild chick some of the wing quills would ripen much later than this, for, in nature, the first quills are not got rid of all at the same time as is the case under farming conditions.

The ventral or underbody feathers of the juvenal plumage are white or light gray in both the cock and the hen, but by 16 months some of the true blacks are beginning to show in the cocks, and, ultimately, the ventrals are all black in the cocks but remain white in the hens.

Under farming conditions the quills of the spadonas are all pulled out at from 8 to 9 months, and the wing quills of the juvenal begin to show in about a month's time. They have been found experimentally to grow at the rate of from 1 to 2 inches per week. The juvenal wing plumes, known as "first-after-chicks," are sometimes uniformly white in the cock, though usually they are tipped with black. Rarely some of the juvenal wing plumes in the hen are pure white; generally they are tipped with black or have an irregular admixture of gray, and though sometimes longer, are usually not as dense nor as valuable as those of the cock. The juvenal wing plumes are much larger than the spadonas and more rounded at the top, but the wing

plumes do not reach their full size until the next stage or even later. As a result of the highly stimulating conditions of artificial feeding, it is found, however, that the plumes tend to attain maturity at the juvenal stage, and advance but little afterwards. This is more especially the case in some strains than in others.

The juvenal tail quills of the cock are now white or tinged with light or dark brown; those of the hen are usually a darker or lighter mottled gray. The juvenal upper and under wing coverts are, like the body feathers, gray or blackish, darker in the cock than in the hen. The small black feathers of the neck and head now disappear to a large extent in both sexes, so that the dark longitudinal bands of the chick are scarcely recognizable. The covering of the head and neck becomes a pale gray, almost white in some strains, and often a pure white ring intervenes between the neck and the body feathers.

With the juvenal plumage slight sexual distinctions begin to manifest themselves. Generally the body feathers are darker in the cocks than in the hens; the ventral or under feathers are white in the latter but change to black in the former; the wing quills of the cock are pure white, usually tipped with black, while those of the hens are nearly always tipped or tinged throughout with gray. The plumage distinction between the sexes is, however, by no means so decided at the juvenal stage as later on, when the true blacks appear in the cock while the body feathers of the hen retain the dark gray or drab.

ADULT PLUMAGE.

The adult plumage in the cock ostrich is altogether different from that of the hen; even at a glance the two sexes are conspicuously unlike (pl. 3, fig. 2). The full distinction is reached when the birds are about 2 years old, but great variation occurs, some strains completing their changes much before others. The adult cock bird is characterized by the possession of black body feathers and coverts, the hen by drab body feathers and coverts (pl. 4, fig. 1). The difference may perhaps be better appreciated by saying that the hen retains throughout life the same dull gray color which she had in the juvenal plumage, while the cock passes through the juvenal to a stage where the feathers are black. Both sexes are practically alike in color as far as the juvenal plumage, and the hen retains the somber color throughout life while the cock goes a stage further in which he is more conspicuous. Similar sexual relationships hold in many other animals, the female remaining at an earlier developmental stage which is common to both, while the male assumes another more showy garb, differences which may perhaps have a bearing upon questions of sexual selection and protective resemblance.

In young cocks there is a marked contrast between the gray or drab feathers of the juvenal plumage and the first black feathers

of the adult plumage. The time at which the true blacks show themselves varies much in different birds, and as these feathers are of greater value than the drabs, the earliness is a matter of some economic importance. The blacks on the sides will sometimes appear before the birds are a year old, but usually they are later, though before the end of two years all the body feathers and coverts will be black. Often in birds between 18 months and 2 years a few odd faded feathers of the juvenal plumage are conspicuous among the fresh true blacks.

With the fourth plumage, "second-after-chicks," the valuable wing quills of both the cock and the hen have usually reached their full size and show their best characteristics. The plumes attain ripeness by the time the bird is about 2 years old, though in forward birds the quills also will be ripe by this time. With the exception of a few feathers toward each end of the wing, the wing quills are pure white in the cock ("primes" or "whites"), but are usually tinged with gray or black in the hen, either throughout or only at the tip ("feminas") (cf. pl. 4, fig. 2; pl. 5). The detailed characters of these feathers, which determine their value from a commercial point of view, will be described later.

The tail quills of the adult also differ in the two sexes. Those of the cock are usually white below and yellowish brown above, while in the hen they are mottled light and dark gray, the proportions of the light and dark areas varying much. At first sight the brown color of the cock's tail feathers might be supposed to be merely a discoloration from dragging over the ground, but it is found to be the true natural color of the plumes in most cases, though some are nearly pure white. As the cocks generally carry their tails erect or pointing forward, the light brown feathers stand out very conspicuously against the blacks of the body.

Except as regards position the passage from the wing and tail quills to the coverts and body feathers is gradual. Toward each end of the series of wing quills three or four of the plumes of the cock, instead of being pure white, are a particolor of black and white. These are technically known as byocks or fancies (pl. 6), and are very attractive plumes, realizing good prices. The hen likewise shows "hen fancies," a mixture of white and gray. Similarly with the two rows of wing coverts; while usually wholly black (pl. 7) or drab, many are white in places, particularly toward each end of the plume. Likewise the white and brown tail quills of the cock are not succeeded by wholly black feathers but by particolored feathers, in which the white, brown, or black are displayed in varying proportions. These intermediate tail feathers are known as "black butts."

As previously stated, the neck and head of the ostrich are covered with small downlike feathers, giving these parts an altogether dif-

ferent appearance from the rest of the body (pl. 3, fig. 2; pl. 4, fig. 1). Examples of the neck and head feathers as they occur in the adult ostrich are shown in plate 8, figure 1. In most cock birds a conspicuous ring of small white feathers occurs toward the base of the neck; that is, where the black body feathers pass into the gray neck feathers (see the cock in pl. 4, fig. 1). Two of these are shown in plate 8, figure 1, and reveal that a few of the barbs at the tip are prolonged beyond the others in a hairlike fashion. This character becomes more emphasized in the feathers covering the rest of the neck and head, as shown in the same illustration. They are downlike in character, the quill and shaft undeveloped, the barbs delicate and hairlike, and the central barb prolonged much beyond the others. Owing to these long barbs the neck and head seem as if provided with a sparse covering of hair, which is especially concentrated as a circular tuft around the ear openings and also around the eyelids, forming the eyelashes.

The under or ventral body feathers are small and black in the cock but white or gray in the hen. In the adult the feathers have all or nearly all disappeared from the upper part of the leg, which is then naked throughout its length; the original feather sockets show, however, for a long time.

The third and fourth clippings are generally considered to represent the best efforts of the ostrich in the direction of feather production (pl. 8, fig. 2). The plumes do not improve from this time onward, so that the farmer is now fully aware of the feather value of his bird. Ostriches which are well treated continue to produce feathers of the same quality for a number of years, well authenticated cases being known of birds 35 to 40 years old which still produce a good plumage. Where, however, the production is forced, as in securing a clipping every eight or nine months, some birds are found to deteriorate after four or five years; but great variation is observed in this respect. The plumes also depreciate rapidly if the practice is followed of drawing the feathers or quills before they are fully ripe. A bird almost useless for feather production may yet be valuable for breeding.

A few general considerations call for notice. The approximate ages given above at which the wing plumes attain ripeness only apply to ostriches under domestication, in which evenness and greater frequency of growth is attained by pulling the quills immediately on attaining ripeness. By this means clippings are secured at 6 months, at 14 months, and at about 2 years, the last representing the adult plumage. When left to themselves; that is, when not drawn artificially, the quills are not all molted at the same time; some will remain in their sockets for months longer than others and hence

delay the plumage stage of the particular socket. The natural order according to which the various plumes appear has not yet been determined, but it is well established that the feathers toward both ends of the wing develop in advance of those in the middle. It follows from this irregular molting that, in a state of nature, the time at which all the wing plumes, tail plumes, and even the coverts have reached the adult plumage stage will be much later than that given above. In a wild ostrich only a few of the wing plumes are growing at any one time instead of the full number as in the domesticated bird, where the growth is regulated artificially.

1. NATAL OR BIRTH FEATHERS, CONSISTING OF TUFTS OF PLUMULES WITHOUT ANY SHAFT BUT WITH A SHORT TERMINAL QUILL.

Some of the plumules are continued into bristle-like portions, which produce the bristly appearance of the chick as a whole. All the feathers of the chick on hatching are of this type.

2. GROUP OF CHICKS A FORTNIGHT OLD, SHOWING THE BRISTLY NATURE OF THE NATAL OR BIRTH PLUMAGE.

Owing to the heat of the day when the photograph was taken the feathers are standing erect and allow the naked parts of the skin (apteria) to be seen, both behind and at the sides.

1. A GROUP OF CHICKS ABOUT 5 MONTHS OLD, SHOWING THE MOTTLED CHARACTER OF THE CHICK PLUMAGE.

Each body feather is tapering and light brown at the tip, while the rest of the feather is dark gray.

2. SPADONAS OR SPADS, THE FIRST WING QUILLS OF THE CHICK, CLIPPED AT ABOUT 6 MONTHS.

The middle one still bears the natal feather at its tip.

1. CHICK A LITTLE OVER 6 MONTHS OLD BEGINNING TO LOSE THE MOTTLED CHARACTER OF ITS PLUMAGE.

The juvenal feathers have appeared along the side and are temporarily tinged with white at the rounded tip. The feathers have almost disappeared from the leg; the neck is more uniform in color than in younger birds, and the ventral body feathers are light gray. The wing being extended, the naked part of the body underneath is clearly seen.

2. A SMALL FLOCK OF FEATHER BIRDS MOSTLY IN FULL PLUMAGE.

Note the black body feathers of the cocks and the drab plumage of the hens. The wing quills are white in both.

1. A PAIR OF BREEDERS, SHOWING THE DIFFERENCE IN THE PLUMAGE OF THE COCK AND HEN.

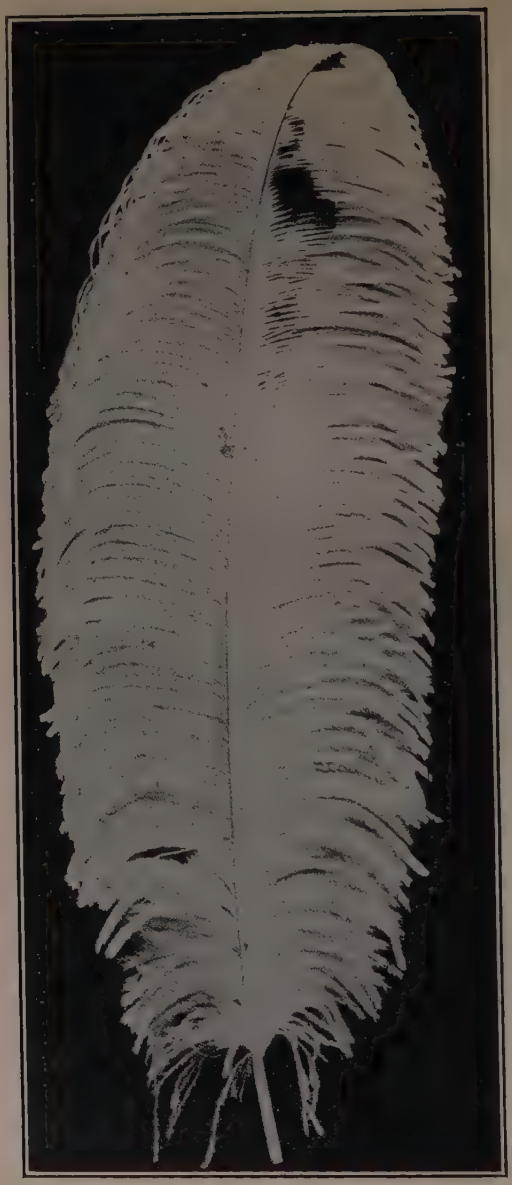
The neck and head are covered with down and uniform in color, except for the white ring toward the root of the neck in the cock. The leg is wholly devoid of feathers; the large scales along the front of the tarsus can be recognized.

2. A COMPLETE CLIPPING OF "FEMINAS," THE WING QUILLS OF THE HEN, DISTINGUISHED BY THE BLACK PATCHES AT THE CROWN OF THE PLUMES.

The clipping weighed 9 ounces. Grown by Mr. James Ford, Kasouga.

A COMPLETE CLIPPING OF THE WING QUILLS, "PRIMES," OF THE COCK, SHOWING THE PURE WHITE OF THE PLUMES.

The few black and white feathers toward the back of the bunch are Fancies or Byocks. The clipping weighed 9 ounces. Grown by Mr. James Ford, Kasouga.



A COCK BYOCK OR FANCY, A PARTI-COLOR OF BLACK AND WHITE.

Three or four of such plumes, often with more black, occur toward the end of the series of wing quills. Grown by Messrs. Walter Weeks & Son, Sandflats.

A CLIPPING OF BLACK WING COVERTS.

In clipping, only the first and second rows of wing coverts are taken.

1. FEATHERS OR DOWN TAKEN FROM THE NECK AND HEAD OF AN ADULT BIRD.

The two larger, one at each side of the group, are from the white ring toward the base of the neck of the cock, the long hair-like middle feather is from the head, and the others from the neck. The "hair" is seen to be a greatly elongated barb.

2. A HIGH-GRADE PRIME, SHOWING CONSIDERABLE NATURAL CURL.

Bird owned by Mr. F. W. Holland, Despatch; bred by Mr. Oscar Evans, Melrose.

MANIFESTED LIFE OF TISSUES OUTSIDE OF THE ORGANISM.

By Alexis Carrel and Montrose T. Burrows.
(From the Laboratories of the Rockefeller Institute for Medical Research, New York.)

I. INTRODUCTION.

Fragments of tissues and organs of mammals and other animals can be kept outside of the organism in a condition of manifested life, when they are placed under certain conditions in a proper culture medium. Their life is essentially characterized by an active growth of the cells from the original fragment into the medium where they undergo direct or indirect division. These cells cover a wide area of the medium, and are often very densely packed. They grow during a period of time which varies from 5 or 6 days to more than 20 days, without any evidence of necrobiosis. The cells which have wandered into or have been born in the plasmatic medium can be transplanted into a new medium and produce a very luxuriant generation of cells. A culture of tumor transplanted into the body of an animal can take and grow rapidly.

The idea of cultivating tissues as previously defined is far from being new. Many experimenters have already thought of the possibility of growing tissues outside of the body, and several have attempted to develop adequate method for it. In 1897 Leo Loeb thought that the culture of tissues in an artificial medium outside of the body was possible, and stated that he had found a method for accomplishing it. But the technique and the results of his experiments have not been published. In 1907 Harrison demonstrated in a series of splendid experiments, made in the anatomical department of Johns Hopkins University, that embryonic tissue of the frog, transplanted into coagulable lymph, will develop normally. The central nervous system of a frog embryo, covered with fluid from the lymph sac of an adult frog, produced long nerve fibers. These experiments demonstrated that the nerve fibers are really an outgrowth from a central neurone. But they demonstrated also a very much more important fact, the possibility of growing tissue outside

the body. At this time Carrel was engaged in the study of the laws of cicatrization of tissues and cutaneous wounds of mammals, and resolved to use for that purpose the method of Harrison. Then Burrows, under the guidance of Prof. Harrison himself, adapted the method to the cultivation of tissues of the chick embryo; that is, of a warm-blooded animal. Then, in September, 1910, at the Rockefeller Institute we succeeded in cultivating in vitro, adult tissues of mammals.

We used at first the culture method of Harrison, that is, of small pieces of tissue suspended in a hanging drop of plasma. Afterwards we developed a method of culture on a plate, which permitted us to grow large quantities of tissues. It became therefore possible to observe many new facts.

It was found at first that almost all the adult and embryonic tissues of dog, cat, chicken, rat, and guinea pigs could be easily cultivated in vitro. According to their nature these tissues generate connective or epithelial cells, which grow into the plasmatic medium in continuous layers, or in radiating chains. The tissue fragments may surround themselves completely with dense new tissue, or, on the contrary, the new cells may spread over the surface of the medium. We observed the direct division of the nuclei during the life of the cells, and many karyokinetic figures in the fixed and stained cultures. Other experiments showed that the life in vitro of the tissues, which varies from about 5 days to about 20 days, can be prolonged by secondary and tertiary cultures, and that a new generation of thyroid, splenic and sarcomatous cells can be obtained from cells which have developed outside the body. We succeeded quickly also in cultivating malignant tissues such as the Rous chicken sarcoma, the Ehrlich and Jensen sarcoma of the rat, a primary carcinoma of the breast (dog) and two human tumors, a sarcoma of the fibula, and a carcinoma of the breast. A culture in vitro of the Rous sarcoma transplanted into a chicken caused the development of a sarcoma. Meanwhile the method has been applied successfully in the laboratory of Prof. MacCallum by Drs. Lambert and Hanes, who cultivated the Ehrlich sarcoma of the rat. We applied also the method of cultivation of tissues in vitro to several problems of the redintegration of normal tissues and of the biology of malignant tumor.

The results obtained in this and other laboratories are already too numerous to be described in this article. We will indicate only the technique, the general characters of the cultures, and some of the applications of this new method.

II. TECHNIQUE.

The new technique consists essentially in depositing small fragments of living tissues in fluid plasma or in an artificial medium. The cultures belong to three types—the small cultures in a hanging

drop, similar to those of Harrison; the cultures in a watch glass filled with plasma; and the large cultures on the surface of a plate, which can be compared to the plate cultures of bacteria. The technique must be elaborate in its details, in order to obtain results which are uniformly positive. Tissues, especially the higher adult mammalian tissues, are easily killed by drying, chilling, and rough handling during the preparation of the culture. Bacterial infection is also detrimental to tissue growth. A rigid asepsis is necessary for the preparation of any tissue culture. The culture must be made in a warm, humid operating room, with the same care and rapidity as a delicate surgical operation. If the method is to give uniform results, not only must the above precautions be closely followed but also the perfect teamwork of well-trained assistants is necessary.

The plasma is prepared from the blood of the animal whose tissues are to be cultivated or from another animal from the same or from different species. The blood is taken from an artery or from a vein. When dogs, cats, chickens, guinea pigs, and rats are used, the carotid artery is ordinarily selected. For human beings the blood is easily obtained from one of the superficial veins of the arm. The animal is etherized and the vessel is exposed and dissected from the surrounding tissue. The wall of the blood vessel is rubbed with dry gauze and covered with olive oil, the circulation is then interrupted by a serre fine, the vessel wall is opened laterally, and a glass cannula previously sterilized in olive oil is inserted into the lumen of the vessel. It is also possible to use a needle sterilized in olive oil and inserted through the skin into the vein. The blood is collected in small tubes, carefully coated with paraffin, which have been previously cooled at 0° C. The tubes are immediately corked, placed in large tubes filled with ice, centrifugalized for five minutes, and deposited in a small ice box at 0° C. The supernatant plasma is removed with pipettes coated with paraffin. It is generally used immediately, but it can be preserved for some time in a fluid condition if it is kept at a low temperature. Artificial media are also employed. They are composed of agar, glucose, and salts under proper concentration. We used also the medium described by Lewis and composed of bouillon, agar, and Ringer solution.

The tissues used for cultures must be in normal condition. They are best if taken directly from the living animal or from an animal soon after death. With a cataract knife and a fine needle, a small fragment of tissue is dissected from the animal and placed on a glass plate. This piece of tissue is rapidly cut into small pieces about the size of a millet seed and transferred on the point of a needle to the surface of a cover glass. For the large cultures, the tissue is cut into small pieces with sharp scissors, or, what is still better, into thin, broader pieces with a razor. It must be remembered that Christiana

has demonstrated that a small piece of thyroid may die if exposed to the drying action of the air for more than 10 seconds. Therefore, the section and the handling of the tissues must be very rapid, otherwise the tissue is killed. The dissection of the tissue may be made in a drop of serum, in order to prevent that accident.

The small cultures are similar to those used by Harrison. One or two small pieces of tissue are transferred to a cover glass and quickly covered with a drop of plasma. It is best to spread the plasma in a thin layer over the cover glass. This is done with the needle before coagulation occurs. The cells grow, then, in a few planes and in areas about the tissue. If the drop is thick the cells grow in many planes and it is difficult to measure the area of growth or to photograph and observe the growing cells. The cover glass is then inverted over a hollow slide with paraffin to prevent drying. The finished slide is immediately placed in a small electric incubator which is used for transferring the cultures from the operating room to the large incubator in the room where the study of cultures is made. Coagulation of the plasma takes place either immediately upon the addition of the tissue or soon after the slides are placed in the warm oven.

To grow tissues on a large scale, the same general technique is used. A rigid asepsis here is most necessary, as it is very easy to infect these large cultures. An entire chicken fetus of 15 days, or small mammalian fetuses cut into small fragments, may be used for these cultures. These fragments are spread in a thin layer over the surface of a large black glass plate and covered quickly with fluid plasma. As soon as coagulation of the plasma has taken place the plates are placed in glass boxes with cotton sponges soaked in water, which preserve the proper humidity. The boxes are then carefully sealed with paraffin and kept in such a position that the fluid products of the culture may drain to the bottom.

During their growth, the cultures can be removed from the incubator for a few seconds without danger to their life. Certain tissues, like malignant tumor or spleen, grow and extend so widely that their condition can be observed without the use of the microscope. On a hollow slide, the new tissue of a culture of spleen appears as an opalescent area surrounding the primitive fragment. Even the beginning of growth can be diagnosed by the appearance on the sharp edges of the fragment of a very faint and narrow gray band. In the culture on plates the appearance of a whitish color around the fragments of the tissues shows that they are growing. But it is safer to make a few control cultures in hollow slides and to observe their growth with a microscope.

For the study of the cultures we use a microscope placed in a warm stage, the temperature of which is kept constant. The slides can

be kept under the miscroscope for a long time, if necessary, without any danger to the life of the tissue. Before the beginning of the growth, the fragment of tissue appears as an opaque, sharply outlined mass in the clear medium. In the surrounding clear medium the growing cells are easily detected. Camera lucida drawings of the cells can be made when the tissues develop slowly, like cartilage or peritoneum. But even in these cases the motion of the cells and the changes in their shape require that the sketches be made rapidly. The growth of sarcoma or of spleen is often so rapid that it renders impossible an accurate camera lucida drawing. The best method of recording the morphology of the living cultures is to photograph them. But this is often very difficult because the new tissue is dense or the cells are faintly seen, and chiefly because the cells do not grow on the same plane. Generally in a very actively growing culture no cell can be seen distinctly. Even when the outlines of the cells can be distinguished easily under the microscope a sharp photograph of them may be impossible if they are surrounded by cells which have grown on slightly different planes.

For exact cytologic study the cultures are fixed and stained. The cover glass, to which the culture is adherent, is separated from the hollow slides, and immersed in corrosive sublimate, acetic acid, or formalin, or the various preparations of potassium bichromate solutions. Afterwards they are stained in hematoxylin. When the culture medium is spread on the cover glass in a very thin layer, and when the culture is not too old, the cells appear very distinctly and all their structural details are easily observed. When the plasmatic medium is thick, and when the cells have grown in many different planes, serial sections of the hardened culture are required.

In order to increase the length of a primary culture secondary and tertiary cultures are made. A secondary culture is obtained from a primary culture by extirpation with a fine needle of the fragment of original tissue, which is deposited on a cover glass and covered with fresh plasma. A second generation of cells can be obtained from a primary or secondary culture by two procedures, one consists of extirpating the fragment of tissue from the culture medium and of covering the free space with fresh plasma. Then the cells from the old plasma grow into the new plasma. The other consists of cutting with fine scissors fragments of medium containing the cells from which a second generation must be obtained. The fragment is deposited on a cover glass and covered with plasma.

The cultures can be grafted under the skin of an animal. Small cultures, or large cultures on plate are used. A fragment of the medium containing the living cells is cut with a knife and introduced into the tissues of the animal.

III. RESULTS.

It is not possible to give in this article a complete description of the results already obtained. We will only describe the main characteristics of the cultures during the different periods of their growth.

Almost all our observations have been upon primary cultures, the phases of which can be divided artificially into three periods, namely, latency, growth, and death.

1. The latent period covers the time from the inoculation of the fragment in the plasmatic medium until the appearance of the first cells. Note must first be taken of the appearance of the culture immediately after its preparation; the fragment appears as an opaque body with more or less sharply defined edges lying within a clear medium.

The length of the latent period varies according to the nature of the tissues. It is very short for embryonal tissues and for malignant tumors, which begin to grow 2 or 3 hours after the preparation of the culture. In some cases, even, the first evidence of growth can be observed after one hour and a half. The latent period of adult tissues lasts generally from 24 hours to 3 or 4 days. It endured from 20 to 72 hours for glandular tissues like kidney, ovary, and thyroid, according to the age of the animal and some other conditions. In the case of a 6-day-old kitten growth began in 12 hours; in that of a young dog it began after 24 to 48 hours. In the case of adult animals 2 to 3 years old the period extended to 48 or 72 hours. The cultures of connective tissue, peritoneum and cartilage, may remain without any evidence of growth for 3 or 4 days.

2. The period of growth varies considerably. It is indicated by the appearance, in one or several regions at the periphery of the fragment, of many small points. They are the ends of the fusiform cells which wander from the tissue. In the cultures of spleen the original fragment is surrounded very soon by a thick crown of round cells with amœboid movements. In the cultures of Rous sarcoma these cells can often be seen in less than 2 hours, but in certain cultures of kidney of 2 or 3 year old cats the first fusiform cells appeared after 4 days. It happens also that the growth begins by epithelial cells, especially in the cultures of thyroid. Generally the wandering and the proliferation of the cells are very active and the fragment of tissue reaches the period of full growth. However, in the cultures of peritoneal endothelium and of cartilage, a few cells only may be seen during several days around the fragment, until the period of active growth begins. The beginning of the growth can often be diagnosed without a microscope by the appearance of an opaline band around the tissues. The period of active growth may extend from 3 or 4 days to more than 25 days. The tissues like sarcoma and cer-

tain embryonal tissues, which grow rapidly, die early, while the cultures of peritoneum and of cartilage, which develop slowly, may remain in excellent condition for 20 or 25 days. The growth of the culture is often very active. From the surface and the peripheral part of the fragment a great many cells wander out and radiate through the medium. They often form a new tissue around the original fragment. The surface covered by the new cells may be very large. In a culture of spleen artificially stimulated this surface was, after 27 hours, almost equal to forty times the surface of the original fragment.

The morphologic characters of the culture vary according to the nature, epithelial or connective, of the tissues. The growth of connective tissue cells was observed mainly in the cultures of spleen, cartilage, and thyroid. The connective tissue cells do not give rise generally to a continuous layer, as we have observed the cells of the epidermis to do. They invade the medium either as isolated single cells or in rows or chains of cells. Ultimately their processes unite to form an open network. In the cultures of peritoneum the cells may tend for a few days to form continuous layers that spread from the fragment into the plasma. But sooner or later, the rate of growth increases, the continuous layer is dislocated, and after about two weeks the cells spread isolatedly through the medium. In the cultures of spleen the cells can conglomerate around a cotton thread and cover it by a layer having the appearance of an endothelial membrane. The cells are fusiform or multipolar. Their cytoplasm is finely granular, while the nucleus appears as a clear spot, containing one or several nucleoli. In the cultures of Rous sarcoma and of the sarcomata of Ehrlich and Jensen, we have observed many different types of connective tissue cells. Often they possess amœboid movements. Sarcomatous cells, inoculated to a culture of the anterior part of the eye of a fetus of chicken, were observed wandering through the pigmented cells and absorbing their dark granules.

The growth of epithelial tissue was studied chiefly in the cultures of thyroid, kidney, skin, and carcinoma. The thyroid cells are polygonal in form and appear somewhat later than the fusiform cells. They present less distinct outlines and a finely granular protoplasm surrounding a large clear round nucleus, which in turn contains one or two opaque nucleoli. These cells differ from the others in remaining in a community and not wandering separately into the medium, and in producing sometimes tubular formations and sometimes continuous layers. Moreover, these cells grow from the edges of the fragment as far as the upper surface and in a single plane. In one instance, the tubular proliferation was traced to the circumference of a thyroid vesicle which formed its base. In some instances the growth was cup shaped, and later budding occurred, so that rami-

fying tubules were produced. In the cultures of kidney, tubules, the wall of which is covered with epithelium cells, may grow out from the original fragment. We observed also chains of large epithelial cells radiating out from the fragments of liver. From the edges of fragments of skin grow out layers of epithelial cells, which cover sometimes a surface larger than the surface of the original fragment.

Epithelial and connective tissues cultivated in vitro increase really in size, and the new tissue is formed by the wandering of the cells from the original fragment and by their multiplication. Camera lucida drawing of a rapidly growing sarcoma showed that the original fragment of sarcoma and of spleen grows very actively, the original tissue resolves itself in living cells after a few days and disappears almost completely. At the same time there is multiplication of the cells. In the cultures fixed and stained with hematoxylin, karyokinetic figures may be seen on all the surface covered by the new cells. In slowly developing cultures of peritoneum we have seen karyokinetic figures 14 days after the preparation of the culture. We have observed also in living cultures direct division of the nuclei and the production of giant cells. The multiplication of the cells can easily be followed under the microscope. When a fragment of plasma containing a few cells is extirpated from a culture of spleen or of thyroid gland and transplanted into a new medium the cells can easily be observed. During the hours and the days following the preparation of the new culture, the cells are seen increasing in number, wandering out from the plasma and invading the new medium. After a few days a very large number of cells have grown from the few transplanted cells.

It seems, therefore, that in our experiments there is a real cultivation of tissues, since the fragments of tissues grow progressively into the culture medium, that the fragments of kidney, thyroid gland, liver, and skin produces tubules, chains, or continuous layers of epithelial cells, since the fixed cells of the tissues, instead of becoming necrotic, may wander into the medium after more than 10 or 12 days, since this medium contains many karyokinetic figures and since a few isolated cells can be seen producing a very large number of new cells.

During the development of cells the culture medium undergoes marked modifications. Sometimes the plasma does not coagulate, or, as it happens in the cultures of human carcinoma and of certain glandular tissues, it coagulates and after a few hours it liquefies again. In these cases no growth is observed. Generally the clot remains firmly adherent to the cover glass and to the tissue. If a part of the fragment is dead a retraction of the plasma may occur in this point after a few days. When the tissue grows normally,

and when all its parts are active, the culture medium becomes progressively modified and undergoes after some time a partial liquefaction, or it becomes opaque, and the fibrin becomes more apparent. The rapidly growing organs, like the kidney, the liver, and occasionally the thyroid, bring about early modifications of the culture medium, while the slowly growing tissues modify it very slightly. After three or four days, the plasma of a culture of sarcoma or of fetal kidney undergoes often a marked retraction. But the plasma of a culture of peritoneum or of cartilage may be, after 18 days, in perfect condition.

3. The diminution in the rate of the proliferation of the cells and the death of the culture depend in a large measure on the condition of the culture medium. Death is preceded by a period of slow growth, during which larger granulations appear within the cells. The cellular outline becomes less sharp. Afterwards, the disintegration occurs and the cells appear as small spherical bodies. The length of life of the tissues can be increased by secondary and tertiary cultures. The new cells can also be transplanted in a new culture medium. If a culture of malignant tumor is grafted under the skin of one animal it may grow and produce a new tumor. Fragments of this tumor can be cultivated in vitro and grafted afterwards to another animal. The duration of the life of the cultures is increased by the procedures which permit of giving to the tissue an almost normal nutrition.

IV. APPLICATIONS.

The method of cultivating tissues outside of the organism has already permitted Harrison to demonstrate that the nerve fibers are really an outgrowth from a central neurone. But it can be applied also to many other problems. We have already used it in studying the characters of growth of malignant tumor, of the growth of normal tissues, and the laws of their redintegration.

Experimental and spontaneous malignant tumors grow easily in vitro. Fragments of Rous sarcoma or of Ehrlich sarcoma grow often very rapidly in the plasmatic media. In less than 48 hours the cells cover a large area. Therefore the modifications in the rate of growth brought about by the action of different kinds of plasma or by the substances artificially placed in the culture medium can be studied easily. It is possible also to study the reactions of normal tissues toward the plasma of animals bearing a tumor. The results of the experiments can be controlled by grafting into animals the tissues produced in vitro. It can show whether the tissues have undergone, during their life outside of the organism, dynamic changes, which persist when they are given back their normal condition of growth inside of the organism.

It was attempted also to study the action of the changes in the composition of the medium on the rate of growth of normal tissues. Slight modification of the tension, or of the alkilinity, or of the concentration of the inorganic salts modified the rate of growth. It may be possible to discover by this method the physicochemical factors which regulate the growth of each kind of tissue.

It would be important to know why and how a wound heals. The laws of cicatrization are actually unknown. Surgeons content themselves by preventing the infection of the wounds and leave to nature the care of healing it. However, if we knew the physico-chemical mechanisms, which, coordinated by the power of redintegration acting as a directing idea, bring about the healing of a wound, we might act on the process of the cicatrization itself and activate it. The knowledge of these laws would lead to a new and more effective form of surgery. But this study is very difficult on living animals, while by cultivating tissues in vitro, in a given medium, it becomes possible to observe exactly the modification in the rate of growth under the influence of certain substances. In this laboratory, Dr. Ruth has observed that small wounds made in the center of a fragment of skin heal normally in vitro. All the stages of the cicatrization can be followed. The edges of the wounds are brought together, and at the same time, the epithelium proliferates, and a complete epidermization of the surface of the small wound occurs. This method permits us to observe very easily the different stages of the cicatrization and the modifications of it produced by the changes in the composition of the medium.

The solution of various problems may be helped by the use of this method of cultivation of tissues in vitro, because it renders possible the observation of cells growing under given conditions. It is a new instrument which can be used in the study of the mechanisms of cellular growth and of its unknown laws.

THE ORIGIN OF DRUIDISM.

By Julius Pokorny.[1]

Schrader, in his Reallexikon der indogermanischen Altertumskunde, says: "The Celtic Druid caste stands outside of all priestly connections of ancient Europe. The impulses to its formation remain shrouded in darkness." I hope to succeed in bringing some light into this darkness.

In the attempt to find the origin of Druidism the most curious ideas have been resorted to. Some consider the Druids as disciples of Pythagoras, others as Buddhists, and the origin of Druidism has been variously traced to Phenicia, Chaldea, and India. Already the ancients showed a keen interest in this priesthood, and the past two centuries produced a large literature on the subject, which, however, is of little value, for it is too much given to symbolical and occultistic fancies. Nevertheless, until now no one could shed further light on the history of the Druids or explain apparent contradictions. When, therefore, in 1906, there appeared "Les Druids et les Dieux Celtiques à Forme d'Animaux," by the noted French Celtist d'Arbois de Jubainville, the scientific world hoped to at last be enlightened concerning this enigmatic institution. But d'Arbois offers scarcely more than a synopsis of the most important things that we already know about the Druids; he gives an historical survey of the invasion of the Celts in Britain but says nothing which we do not already know from other sources.

In the first chapter of his book, speaking of the priests of the Gauls, d'Arbois de Jubainville says: "They have two main classes of priests, the Druids and the 'Gutuatri.' When Julius Cæsar in the first century B. C. subjected independent Gaul, the Druids held there an important position; but he was told that Druidism had its origin in Britain and was thence introduced into Gaul."

Prior to the arrival of the Druids on the Continent the Gauls had, besides the vates, no other priests than the gutuatri. He derives

[1] Translated, by permission, from the German (with author's revision): Der Ursprung des Druidentums. Von Julius Pokorny in Wien. Lecture delivered in the monthly meeting, November 13, 1907. Mitteilungen der Anthropologischen Gesellschaft in Wien. Vol. 38, 1908, pp. 34–45.

their name from the Celtic gutu, Irish guth (voice), and compares our "Gott" (God), which originated from the Indo-European Ghuttom (that which is invoked), from the root ghu. "Gutuatri" thus means "the invokers" from the same root as the Gothic gudja (priest). They were all priests of a temple or sacred grove. The gutuatri survived down to the time of Roman rule; their names are preserved on four inscriptions. D'Arbois quite properly compares the gutuatri with the Homeric ἱερευς (hiereüs—priest), with Chryses, who has the surname of ἀρητήρ (areter—the praying one), which has the same meaning as gutuatros, and as the flamines of the Romans, who formed no corporation. He says:

> The Druids, on the other hand, formed a corporation, with a chief Druid at its head, in Gaul, Ireland, and probably also in England.

I can not agree with D'Arbois in the last statement. In Irish literature no mention is made of a chief of the Druids. From the passage from the Life of St. Patrick, "A great multitude of soothsayers gathered around the chief soothsayer, Recradus by name" (Congreata est multitudo nimis magorum ad primum magum Recradum nomine), it can not be concluded that the Irish Druids had a supreme head. The passage can also mean that Recradus was at that time the most famous Druid; we may even credit the Christian writer, who wished to magnify the fame of the saint, with a little exaggeration, for farther on is narrated how St. Patrick had by a miracle killed that Druid. The chief Druid is thus a specifically Gallic institution.

In the art of soothsaying the Druids had rivals in the *vatis*, who are called by Strabo οὐάτεις (ouateis), by Diodorus μάντεις (manteis). St. Patrick triumphed over the Druids only after he had allied himself with the *vatis*, Irish, *fáithi*, *filid*.

D'Arbois derives, with Thurneysen, the name of the Druids from the root *dru-* (Irish in *dron*, from *dru-no*, strong) and the root *vid* (compare Latin *videre*, to see, German *wissen*, to know) and renders the name druis (from *dru-vid-s*) "supreme-wise," the Galatian drumenton, "chief-sanctuary," quoting the Gallic synonym, *ver-nemeton*. (Still there are other derivations of *druis* possible. Compare Cymrian *derwydd*, Gallic *dervum*.)

The second chapter seems to me the most important of the whole book. I shall therefore give it almost complete in translation.

> It seems that the Druids were known to the Greeks since about 200 B. C., when Sotion speaks of them. They thus existed already at that time in Gaul, this side of the Rhine, a territory which was much frequented by traders from Massilla. This was not long after the Gauls had conquered Britain, which was occupied by the Gaels.[1]

[1] Already before the appearance of Zimmer's work I had pointed out in the Mitteilungen der Anthropologischen Gesellschaft in Wien, volume 39, page 94, note 3, that the Gauls could have come to Ireland directly from the continent without touching

And, indeed, this conquest seems to have taken place between 300 and 200 B. C. The Gauls found the Druids in Britain and transplanted this institution to the continent. Julius Caesar says explicitly: "It is assumed that the system found in Britain was thence transplanted to Gaul, and at present those who desire to know it more carefully mostly go thither to obtain information" (Disciplina in Brittania reperta atque inde in Galliam translata esse existimatur, et nunc qui diligentius eam rem cognoscere volunt plerumque illo discendi causa proficiscuntur). We conclude from this that the Druids were originally a Gaelic institution, at first peculiar to the Gaels, not including the Gauls. The Gaels are a Celtic tribe, whose language survives in Ireland and the Highlands of Scotland. By this tribe, who for a long time dominated the British isles, Druidism was introduced into the vast regious south of the Channel between the Atlantic Ocean and the Rhine; but it was unknown in Gallia Cisalpina and in the ancient Celtic territories east of the Rhine, as also in the Danube basin and Asia Minor, where the *dru-nemeton* (chief-sanctuary) is in nowise connected with the Druids.

So far d'Arbois de Jubainville.

Before proceeding there may be given a brief summary of the accounts of the Druids by the ancient writers.

According to Caesar there were in Gaul two ruling classes, the military nobles and the Druids, who were free from military service and from paying tributes. On account of these advantages many were attracted to this vocation, which was quite an easy matter, since "Druidism was based not on birth but on the gaining and training of novices."[1]

The Druids were philosophers and teachers of the youths. They taught not only theology and mythology, but also much of the course of the stars, of the nature of all things, and the magnitude of the universe.

Of all the moral teachings of the Druids only a single sentence is preserved (Diogenes Laertius, proemium, 5): "To be pious toward the gods, to do wrong to no man, and to practice fortitude." But their chief doctrine was that the souls do not die, but pass after death into another body. So strong was the popular belief in it that credit relations were entered upon with the promise to settle them in the other world. The novices had to learn a large number of verses by heart, some of them spending as many as 20 years in study. Of the tradition of the Gaulish Druids almost nothing survived, because

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Britian. And now I am firmly convinced that this theory is the only correct one. It also agrees best with the hoary Irish traditions which report of immigrations from Spain (i. e., western France). The older theory, according to which the Gauls had come to the British Islands already in the tenth century B. C., is not only entirely unprovable but there is everything against the assumption that the Celts had already at that early time penetrated so far westward, as I hope to prove at a later time. The conquest of Ireland is certainly connected with the great movement of the Celtic peoples of the sixth century. From Ireland the Gaels then conquered parts of Wales and Scotland. Somewhere in the fourth century B. C. the Brythonic Celts of northern France conquered Britain, where they met in the west with the Gaels, who had come over from Ireland. A further immigration of Brythonic Celts (Belgae) followed there in the course of the third century B. C.

[1] Schrader, Reallexikon der Indog. Altertumskunde, ii. p. 643.

they strictly prohibited reducing it to writing. The case was different in Ireland. The author of the "Yellow Book of Lecan" relates that St. Patrick burned 180 Druidic books, and, following his example, all the Christians did the same, until all the Druidic books were annihilated. The Druids were also soothsayers, and assisted at sacrifices.

They assembled annually in the lands of the Carnutes, when law cases were submitted to their decision. The utmost punishment that they could inflict was excommunication. Those affected by it were avoided by everybody and treated as outlaws. At the head of the Gaulish Druids stood the chief Druid, who was created, after the death of his predecessor, by election.

Caesar seems to comprise under the name of "Druides" also the bards and seers (vatis) who by later writers are treated separately.

The similarity of the Druidic doctrine to that of Pythagoras gave occasion for many fables. That the Druids did not live as monks (a theory set up by Alexander Bertrand) appears from the fact that the Druid Divitiacus, Caesar's friend, had wife and children, and that the Irish Druids also were mostly married.

Criminals were sacrificed to the gods, but also innocents. Large figures of wicker work were filled with living persons and set afire.

The Romans soon prohibited Druidism, but it continued in secret, and the most prominent Gaulish youth practiced the doctrines in secreted woods, as Mela (45 A. D.) relates.

Thirty-five years later Pliny the Elder draws an entirely different picture of the Druids. He shows them as priests of the oak, as physicians and sorcerers, as common charlatans. They prepare from the poison of snakes the mystic egg which guarantees the winning of every lawsuit.

How is this change to be explained? Was it a result of their suppression that they laid aside their lofty doctrines in order to make a living in a less dignified way? It will presently be shown that the Druids had been ere that necromancers. But how is it to be explained that alongside of such serious knowledge they engaged in low sorcery? For the present it will suffice to point out that often the wisest men are the greatest charlatans, since they know that the large majority is governed not so much by lofty wisdom as by cunning trickery.

As regards the belief of the Druids in immortality and the doctrine of transmigration, d'Arbois quotes many examples for the belief of the Celts in a continued existence in the other world, but declares the assumption of the doctrine of reincarnation an error which arose from the fact that the Greeks who heard of Druid myths in which transformations occurred falsely interpreted them and thus came to the belief that the Druids taught the transmigration of souls after the belief of Pythagoras.

Another conjecture may be permitted here. May we not see in this doctrine a remnant of the belief of the pre-Celtic aborigines? The belief in transmigration is mostly found among peoples of low culture, and the next step is reincarnation, of which, indeed, Irish myths exhibit some instances.

D'Arbois has shown that the Druids were originally the priests of only one Celtic tribe, who first conquered a part of Britain. Now, it is passing strange that between brother tribes, whose customs, manners, and language did not vary much, there should have existed such a fundamental difference. For nothing characterizes a people better than its religious views. Druidism, as will be seen, is contrary to Indo-European religion. There is only one way to explain such a peculiar, almost essential difference which should have existed between the Gaels and the Gauls before the conquest of Gaul by Cæsar.

It is true that the Gauls received Druidism from their brothers in Britain, but these latter likewise did not have the institution when they crossed the channel; for the Druids were the priests of the pre-Celtic aborigines of the British Isles, and were adopted from them by the Celts.

The Gaels, a main branch of the Celts, when, in the fifth or sixth century B. C., they conquered Ireland, and from there parts of Wales and Scotland, had already attained to a higher grade of civilization. Their rulers were priest kings, whom at that time we also find among the Greeks, Latins, and Germans, with whom the Celts shared many other traits of Indo-European descent. We have no reason to assume that at that early time the Celts differed much in custom and religion from their surrounding Indo-European brother tribes, which would have to be supposed if the institution of Druidism existed with them from prehistoric times. Even in historic time there are found with the Irish kings traces of the former priesthood, which had developed in the remotest past from the divine veneration of mighty sorcerers; for the belief of the savage that his divine[1] ruler is the center of the universe, who with a motion of the hand can upset the course of nature, and therefore can protect him from the dangers which, in his opinion, threaten every common mortal through innumerable taboos, was also once held by the Indo-Europeans, though long before they had left their common cradle.

Such belief in the divinity of kings appears in Homer, when he speaks of a king (Odyssey, XIX, 109) who honors the gods and mightily reigns, and on account of the piety of the king[2] the earth is fertile and the people prosperous, and traces of like belief appear also in Ireland and Wales. Thus the Celts believed that crop failures

[1] See Frazer, The Golden Bough, London, 1900, vol. 1, pp. 233, 234.
[2] Frazer, The Golden Bough, vol. 1, pp. 156, 157.

were due to the wickedness of rulers. In the "Book of Leinster" is related that under Cairbre Cinnchait, who acceded to the throne by violence and caused the children of the nobles to be pitilessly killed, each ear bore only a single grain, each oak only one cone. But when the old dynasty was restored Ireland regained its fertility. To each new king the Ollamh, the chief bard, chanted some verses, in which he admonished him to reign well, else famine and disease would devastate the land, and in a Welsh poem of the twelfth century is read: "With false kings and [in consequence] failure of crops we will have bad years and (long) days" (the Black Book of Carmarthen).

We hear, besides, of many taboos which the Irish kings, even in historic times, had to observe to keep off misfortune from the land. (Book of Rights, pp. 3–8.)

Thus the high King of Ireland in Tara must not be in his bed when the sun rises. He must not settle on a Wednesday on Magh Breagh, not cross Magh Cuillinn after sunset, not drive his horse on Fan Chomair, not on Monday board a vessel in the water after Bealltaine, nor must he on Tuesday after All Saints leave behind traces of his army upon Ath Maighne.

The King of Connaught must not make a treaty over his old palace after he had concluded peace on All Saints Day (the 1st of November was a Celtic pagan holiday); he must not in variegated dress ride on a gray-speckled steed to the heath of Dal Chais, or visit a gathering of women at Graghais, or sit in the autumn upon the grave of the wife of Maine, nor run a race between two stations at Ath Gallta with the rider of a gray, one-eyed horse.

Similar taboos had to be observed by the kings of Leinster, Munster, and Ulster.

From this it follows that the kings of the Gaels, like the other Indo-Europeans, evolved from priests, and we may conclude, since especially in Ireland the remembrance of it remained so fresh and distinct, that the kings of the Gaels when they conquered Ireland had also been their priests.

As archeology clearly shows, the Celts were obviously not the first inhabitants of the British Islands, but had already found there an aboriginal people. My own unprejudiced anthropological observations during a sojourn in Ireland have convinced me that we have on Irish soil to do with two pre-Celtic, non-Indo-European races.

One of these races, found chiefly in northern Ireland (also in Scotland), is of small, but well-proportioned stature (I was obliged to stoop at almost every door in order not to knock my head), predominantly brachycephalic, with the lower half of the face of unusual length, the profile line running almost straight from the under lip to the chin, swelled, thick lips, slightly prognathic, with black wiry hair and dark eyes, resembling the Samoyeds; the women of a

peculiar, fascinating ugliness, which could almost be called beautiful. We have here undoubtedly to do with a neolithic northern race, perhaps related to the Lapps or Finns. I would like to merely mention here that certain archeological traces point to an early connection between the British Isles and Scandinavia. (British Museum Guide of the Bronze Age, pp. 24, 31, 146.)

The other pre-Celtic race, found chiefly in southern Ireland, is of tall and slender build, predominantly dolichocephalic, with dark hair and eyes, of the Mediterranean type, and so much resembling the Spaniards that there is a common legend that these people are descendants of the Spaniards who, after the destruction of the great armada, found refuge on the coast of Ireland. They can not be Ligurians, as Jullien assumes, because the Ligurians were small and weakly, and the Iberians suggest themselves as the nearest approach to the truth. Numerous other archeological traces of the neolithic and bronze ages point likewise to a close connection between Spain and Ireland. There is added to this the testimony of Tacitus about the Silurians in Wales.

I was not able to pursue close anthropological studies in Wales, still I could also here clearly discern the predominance of the non-Indo-European element. The same traces could also be followed up in Scotland and Cornwall.

But if we assume that the aborigines did not entirely succumb to the invading Celts, and even forced on them their sorcerers, their national consciousness must have been very strong, and this it was, for to the present day it has left its traces in the British Isles.

Passing over the linguistic remains, which have survived in the topography and the Celtic languages, also the innumerable fetish-stones which are met with in the British Isles and which are still venerated—there may be mentioned only a few interesting points out of the rich material.

The testimony of Diodorus and Strabo about cannibalism among the British is confirmed by St. Jerome, who, in his Adversus Jovinianum, says: "What shall I say of other nations when as a young boy I myself in Gaul saw the Atecotti, a British tribe, eating human flesh? And while they have in the woods herds of pigs and cattle they are in the habit of cutting off the soft parts of the shepherds and the breasts of women, considering these alone as delicacies." (Quid loquar de ceteris nationibus, cum ipse adolescentulus in Gallia viderim Atecottos, gentem Britannicam, humanis vesci carnibus? Et cum per silvas porcorum greges et armentorum pecudumque reperirent, pastorum nates et feminarum papillas solere abscindere et eas solas ciborum delicias arbitrari?) Nobody will maintain that such customs can be ascribed to Indo-Europeans. A dim recollection of those times still survives among the Celtic people,

and we find in Wales and Scotland numerous tales of giants and spirits who ate their captives and drank their blood.

Another custom mentioned by Strabo, that the ancient Irish consumed the corpses of their fathers, can certainly not be credited to the Celts, since it is well known what an important part the ancestor cult plays among the Indo-Europeans. This custom goes back to the belief of the savage, that with the blood he also takes in the soul of the dead, and traces of the custom can be followed up even at the present day.

Wood-Martin relates that the still subsisting custom in Ireland of taking food at a funeral in the presence of the dead is a later form of an old custom of consuming the food after it was laid on the corpse, with the object of acquiring certain qualities of the departed. It may be considered as a remnant of the old barbarous custom of consuming the corpse itself.

Schrader has shown that the family conception of the Indo-Europeans in prehistoric times must have been entirely agnatic—the principle of relationship by the father's side was carried through in the common prehistoric time of the Indo-Europeans. When in the British Isles traces of the matriarchate are discovered they must be ascribed to the pre-Celtic peoples.

Zimmer has positively established the fact that among the Picts of Scotland the matriarchate prevailed down to historic times. The Picts are to be sure non-Indo-Europeans, but they were celticized; they had absorbed numerous Gaelic elements at about 500 B. C. from the Irish Gaels, 100 to 200 years later from the "Brythons," and were gaelicized again in the first Christian centuries.

In Wales traces of the matriarchate are found in the families of the Mabinogion, and also as regards Ireland many clear proofs can be adduced.

Matriarchate among the Iberians in antiquity is well attested, and Solinus relates that in Ireland it is the mother that offers to the new born the first food on the point of the sword of her husband, with the wish that he may die in no other way than in battle. On the other hand, among the Indo-Europeans it is the father who gave the child the first food, as is proved in India by the Grihya-Sûtren of the Apastamba and Hiranyakesin,[1] and which Speijer in Jatakarna (p. 103 ff.) has shown to hold good also for the other Indo-European peoples.

F. A. Potter relates (Description of West-Meath, 1819) that all married women call themselves by their maiden names, which is still customary in Ulster. According to Wood-Martin, women retain in many places their maiden names and follow more often the relatives of their mothers than of their fathers.

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[1] M. Mueller, Sacred Books of the East, xix, pp. 213, 281.

The couvade, certainly a non-Indo-European custom, is also found in the British Isles. In Ulster the couvade (men's childbed) was customary in hoary antiquity, for the Book of Leinster relates that when Queen Medb of Connaught marched with an army against Ulster all the men were lying in bed incapable of fighting, with the exception of Cuchulains and his father. A pregnant woman had cursed them so that once a year they should experience the pains of labor of the women.

In England, too, the custom of the couvade once existed, for in Yorkshire [1] the mother of a girl who has borne an illegitimate child used to go out in search of its father, and the first man she finds in bed is the one sought after.

Even for the Iberians is the custom of men's childbed attested, and it is still found among their descendants (?), the Basks. This makes it probable that there was a connection between the aborigines of the British Isles and the Iberians. This custom is also found in southern India, China, Borneo, Kamchatka, Greenland, and among many tribes of North and South America. Irish women before the birth of a child often wear the coat of the husband in order that he share in the pains of labor and thus relieve the wife.

It has been seen that the race of the aborigines of the British Isles was not exterminated by the conquering Celts. It is also certain that it was not completely suppressed, but that the conquerors to a large extent amalgamated with the subjugated. For even in the earliest times there is not found in Ireland a servile plebe as in other countries conquered by the Indo-Europeans. There were there no castes, only different social strata and a family could easily, by the acquisition of riches, rise from the lowest rank to the highest. There was perhaps rather an infiltration of the Celts than a real conquest, but the reason for it may perhaps be justly looked for in the great beauty and the extraordinary charm of the women of the aborigines. The beauty of the Celtic women is well known, also the fact that most of them had black hair and dark eyes, which evidently points to a non-Indo-European descent.

Among no other people does woman play such a great rôle as among the Celts. Their literature is the cult of women. No literature is so rich in love stories as the Irish.

It was pointed out that in the oldest hero songs of most nations women play but a small part, excepting among the Germans with whom women always held an important position. But the position of women in the Celtic tradition is incomparably more important. The love of a man for an immortal or, at least, semidivine maiden regularly recurs in the hero tales. Germans and Celts have treated this subject but in a very different manner. In the tales of the Germans the man plays the chief part; he woos the goddess and sometimes even

[1] The Academy, vol. 25, p. 112.

compels her to rule at his hearth. Usually, however, overcome by the boldness and beauty of the hero, she becomes voluntarily his subject.

Different is the case with the divine mistress of the Celtic hero. She stays in her own land and entices or compels the mortal lover to seek her. Connia, Bran, Ossian have to leave this earth in order to become united with their beloved. Even Cuchulain, the mightiest of all heroes, is compelled, notwithstanding all resistance, to follow the fairy queen Fand and to dwell with her. The divine beloved always retains the upper hand; when the mortal becomes tired and returns to the earth she remains back, wise and beautiful, to bewitch and receive a new generation of heroes. She chooses whom she likes, and is no man's slave. She surrenders freely, but she gives up neither her freedom nor her divine nature. Even when the love story plays among human beings, the position of the women is much more emphasized than in the German tales. She is no mere puppet upon a flame-girt rock who is ready to run straightway into the arms of the hero destined for her by fate. The Celtic woman takes her fate into her own hand and chooses herself her husband or names to him her conditions.[1]

It often happens that the woman woos the man instead of the reverse.

In one of the oldest Gaelic chronicles is read:

But the fairest woman who came with the Milesians to Ireland was Faele, Luaidh's wife who had lived lonely in western Spain till Luaidh wooed her—and people said of Feale she was too beautiful to live.

The Irish historians used to designate as Milesians the non-Indo-European dark-eyed and black-haired people of Ireland whom they considered, on account of their appearance, as immigrant Spaniards.

All this makes possible a great influence of the aborigines on the Gaels. But before assuming the probability that they have exercised such a great religious influence, it is necessary to find an analogy for such an occurrence.

The aborigines of the British Isles stood, as has been seen, on a low grade of civilization—they were savages. Let us first investigate what conceptions one savage people forms of another.

The savage fears everything new and believes it bewitched.

Thus the inhabitants of the Nikobares ascribed the unusual violent rains of 1886 to the anger of the spirits because theodolites and other strange instruments were put up upon their favorite places.[2] The savage obviously considers a foreign country as bewitched. Among the Ovambos the army, when going to war, is preceded by a man who is next to the general in rank, and on the march carries a burning torch. This has probably the object of purifying the air from the evil spirits who inhabit the enemy's country, for when the fire is extinguished it is taken as a bad omen and the army returns.[3]

The inhabitants of a foreign land are the more believed by the savages to be sorcerers, especially when they belong to a strange, less

[1] A. Nutt, Studies on the Legend of the Holy Grail, London, 1887, p. 231–233.
[2] Internationales Archiv. für Ethnologie, vol. 6, p. 13.
[3] H. Schinz, Deutsch-Suedwest-Afrika, p. 320.

civilized race. This same fear is met with not only among savages but also among peoples of a higher degree of civilization.

In the Ontong-Java Islands all strangers at their arrival are solemnly received by the sorcerers, sprinkled with water, then anointed with oil, etc. Only after they have been uncharmed can they be presented to the chief.[1]

It is also known that the Hindus despised the aborigines as unclean, but, on the other hand, also feared them, because they believed that the pariahs were in possession of secret magic virtues and in alliance with the old gods of the country.

It is therefore very probable that the invading Gaels considered the aborigines as beings endowed with supernatural powers and possessing great knowledge of the secrets of nature.

How much superstition is attached among the people of Great Britain and Ireland to the so-called "fairy arrows," i. e., arrow points of flint, which were used by the pre-Celtic aborigines in the stone age. Perhaps this superstition goes back to a time when the Celts warred with a people that employed flint weapons and was already then feared as being endowed with supernatural power. With this agrees well another folk-belief which is connected with iron.

Iron is supposed to have the potency of warding off all spirits.

In northeast Scotland a piece of iron is inserted into all viands in order that "death" should not enter.[2] In many Welsh tales the fairy abandons her beloved at the moment he touches her with a piece of iron.[3]

In the western islands of Scotland it is said that any one who enters the interior of a mountain in which the fairies dance must leave a piece of iron before the entrance. Only so can he prevent the fairies from closing the gate and retaining him forever.

This fear of spirits seems to be an inheritance from the aborigines who had no knowledge of the metals and may have often retreated before the better arms of the Celts. The crude inhabitants of a country often appear in the later popular beliefs as spirits, giants, or dwarfs.

The Celts must have naturally felt a special reverence for the aboriginal medicine men, the Druids, whom they saw feared by their own people. Among savage peoples the king is usually evolved from the sorcerer, who, in their belief, can, through his arts, bring on misfortune and death. With admiration the Gaels called these sorcerers "Druids," the supreme wise.

The peculiar character of the Druids was that of mighty sorcerers, and is in complete contradiction to the conception of an Indo-European priest. In Ireland, which was least exposed to foreign influences, we can best hope to find Druidism in its original form. We

[1] Internationales Archiv. für Ethnographie, vol. 10, p. 112.
[2] W. Gregor, Folklore of the N. E. of Scotland, p. 206.
[3] Transactions of the Hon. Society of Cymmrodor, vol. 4, p. 2.

meet them there chiefly as magicians and jugglers. They can turn day into night, wind and sea obey their words, they can cause fire and blood to rain. Such views as that man has power over the elements are found only among uncivilized peoples, who lack the conception of the supernatural. That the Druids were physicians is closely connected with their calling as wizards, so also their gift of prophecy. So great is their power that even St. Patrick implores God to protect him against the conjurations of the Druids. In old Irish literature the word "drui" is used synonymously with "magus," and in the new Celtic languages the word sorcerer stands for "Druid."

The Druids are sorcerers and rain makers, who pretend that they can conjure storm and snow, and frighten the people through fluttering wisps of straw and other childish tricks. They soothsay by the observation of sneezing and other omens, by their dreams after a festival, or by chewing raw horse flesh in the presence of their idols, by the croaking of their ravens and the chirping of tame wrens, or by licking of a bronze blade, which was made red hot in the fire of a mountain ash. They are dressed, like the medicine men of the redskins or the Angekoks of the Esquimaux, in ox skins, upon the head a bird cap with waving plumes.[1]

In the mountains of Scotland, north of the Grampian Hills, the aborigines remained longest independent, and therefore also longest preserved the institution of the Druids as sorcerers, for we hear that those who wish to learn the nefarious art of conjuring more thoroughly travel to Alba (Scotland).

Pliny the Elder also says that Britain is in bad repute on account of its magic arts, and from the narration of Tacitus of the destruction of the Druid sanctuary at Mona, it becomes evident that the Druids were sorcerers.

But how can it be explained that they should be described by the writers of antiquity as philosophers, as teachers of a pure morality?

In Gaul Druidism rested not on birth, but on the gaining and training of novices; in Ireland, too, we find the Druids as teachers of the youth, and of the Druid Cathbad it is expressly said that he is teaching his pupils the Druidic science (druidecht). It can therefore be safely assumed that also among the aborigines the art of conjuring was conveyed through instruction and initiation.

Where the Gaels entered into friendly relations with them they, no doubt, also endeavored to participate in that instruction, and we find in Ireland not a closed Druid caste, but we know also poets who were Druids; even some kings, as the grandfather of the famous Irish national hero Finn and King Connor's father, belonged to that priesthood. Thus the Druids gradually became a Gaelic institution and the priestly power of the king was also transferred to them so that they held after him the highest rank; it even was the rule that

[1] Compare O'Curry's Lectures who, however, gives another explanation.

the king in the presence of his Druid was not allowed to speak until after the latter had spoken.

A dim recollection of the fact that the Druids were once the sorcerers of a hostile race survives in the Celtic myths, which relate that the magic virtue of the Druids was so great that they even triumphed over the gods, a trait which, on the one hand recalls the shamans, on the other, becomes easily intelligible when it is remembered that the Druids having been originally the sorcerers of the aborigines were the enemies of the Celts and also of their gods.

So also the peculiar contrast between the Druids and the Celtic gods, which, for instance, makes itself prominent in the "Echtra Connla," is explained in this way.

No wonder that the Gaelic poet prophets (Irish, *filid*, *fáithi*, for the Celts had also their soothsayers), considered their new rivals with jealous eyes, a jealousy which finally led to the extermination of the Druids (637, battle of Mayrath) in Ireland, for when St. Patrick wanted to introduce Christianity into Ireland he found in the Druids his worst enemies, and he could only overcome them by allying himself with the *filid*.

It is not strange that the more highly civilized Celts considered the priests of the savage aborigines as mighty sorcerers, since we find something similar among the Germans.

The Finns, who in prehistoric times had occupied a large portion of the Scandinavian Peninsula, were considered by the invading Germans as conjurers, so that old Norse *finngert*, literally Finnish work, is unequivocally used for witchcraft, and in their own religion the wizard, the shaman, who mediates the relations between men and gods, nay even coerce the latter through his art into his service, holds the central position.[1]

Prof. Much calls my attention to the fact that in the Edda poem, Hyndlulioth, p. 31, all sorcerers are derived from "Schwarzkopf" (Blackhead), who by his name is marked as the representative of a non-Indo-European race (Lapps). Thus the Germans, while they knew sorcerers, referred them to the Lapps, a non-Indo-European people. And as the Irish, in order to learn the art of sorcery traveled to Scotland, so we also have the Norse expressions, as "fara til finna" and "gera finnfarar," i. e., to travel to the Finns (Lapps) in order to learn the arts of sorcery.

Is it too rash to assume that the crude aborigines of the British Isles had a civilization similar to that of the Finnish-Lappish peoples? Similar primitive conditions produce similar civilizations, and J. F. Campbell, an eminent authority on Finnish antiquities, was so astonished at the surprising similarity between many Scottish cave-dwellings and those of the Finns that he did not hesitate to declare the aborigines of Britain a people related to the Finns.

[1] R. Much, Deutsche Stammeskunde, p. 31.

When the Gaels allowed their sons to be initiated in the Druid teachings they certainly did not forget their own Indo-European religion, and the same was the case with the Gauls who later conquered Britain and adopted Druidism from its inhabitants as the Gaels had from the aborigines. Thus the peculiar contrast between higher and lower doctrines as found among the Druids is easily explained. When Pliny the Elder described the Druids as merely conjurers and priests of the oak, he told his contemporaries something new; their lofty doctrines were long before that generally known.

There are elsewhere instances of an advanced religion tolerating the old, crude faith. When to the present day in Catholic countries the Adonis festival is observed and the old heathen feasts of the solstices and harvest are tolerated by the church, it can be assumed that in the British Isles even under the domination of the Celts the non-Indo-European religion was in part preserved.

Andrew Lang, in his work "Custom and Myth," quotes an instance of a similar toleration which was transmitted by Garcilasso de Vega, the son of a Spanish conqueror and an Inca princess.

> Before the time of the Incas every Indian believed himself a descendant of a river or of a wild animal and sacrificed to them. But descent was also derived from insignificant creatures, such as frogs and toads. When the Incas appeared and introduced the sun cult, they allowed the old animal worship to persist and the magnificent temples of the sun also harbored images of the animals which the Indians formerly worshiped.

That Druidism had its origin in the British Isles and was not brought thither by the Celts, there is almost certain proof.

Pliny the Elder depicts the Gallic Druids as priests of the oak cult in which also the mistletoe played an important rôle. (Hist. Nat., xvi, 279 sequ.) The worship of the oak as part of the Indo-European religion is well attested and it also can be proven that the mistletoe had a great significance in this cult. The fact is so generally known that it does not require special proof. Besides, Max. Tyrius also says that the Celts worshiped Zeus in the image of a high oak. The Druids are thus seen as priests of an Indo-European cult.

If then the Celts before the conquest of the British Isles already had Druids, who were priests of the oak cult, they would certainly have brought this cult to Ireland; for Ireland was in ancient times exceedingly rich in oak forests and even now there are more than 1,300 place names which begin with "doire, daire" (oakwood), Anglicised "derry"—not to mention other compounds—so that the name of the oak in place names is much more frequent than that of any other tree.[1]

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[1] Joyce, Irish Names of Places, 3d edition, p. 487.

How strange must it then appear that the oak is so rarely mentioned in the rich legendary literature of Ireland. Not a single Irish superstition is known which is connected with the oak, and the Druids in Ireland are never brought in relation to the oak. Their sacred tree is the mountain ash, and they carry in their hands staffs made of this wood. The Druid fire also is kindled with the wood of the mountain ash.

The peculiar fact that the oak plays no part whatever in the life of the Irish Druids and in the superstition of the people can only be explained by the assumption that the Druids were originally priests of a people that did not know the oak cult.

The Gauls who remained longer in their country were less under the influence of the pre-Celtic inhabitants of the British Isles than the Gaels, and therefore preserved alongside of the new Druid doctrine the old customs of their Indo-European ancestors.

It is thus seen that the Druids must once have been the priests of a people that did not know the oak cult. The oak cult of the Celts is repeatedly attested; hence the Druids can not originally have been a Celtic priesthood. It is also known that Druidism took its origin in the British Isles, and it can only be derived from a people which inhabited those lands before the Celts. It has been seen that such a people had existed in the British Isles and that it was strong enough to exercise a decisive influence upon the conquering Celts; it is also known that it is possible and often happens that a people which is lower in the scale of civilization influences the religious conceptions of a more advanced one.

Aside from this, Druidism exhibits so many non-Indo-European traits that on this account alone the origin of this priesthood must be sought amongst a non-Indo-European people.

It can therefore be maintained with great degree of certainty that Druidism had its origin among a people that inhabited the British Isles before the Celts, and probably belonged to those great tribes who dominated western or northern Europe long before the first Indo-European had planted his foot there.

We can even determine the origin of this people still more definitely. Rhys doubts Caesar's statement that Druidism took its origin in the British Isles, because the same pre-Celtic people is also met with on the Continent, and the Iberians of western Europe had Druids. But this difficulty can very well be solved if we assume that Druidism had its origin among the prehistoric people of northern Ireland, who were different from the Iberians. The analogy with the Germanic conditions described above thus becomes still clearer. Caesar's assertion thus remains unshaken.

GEOGRAPHICAL AND STATISTICAL VIEW OF THE CONTEMPORARY SLAV PEOPLES.[1]

[With colored map.]

By Lubor Niederle,
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INTRODUCTION.

The original Slav people arose in central Europe by a gradual linguistic and cultural division from the old Aryan or Indo-European units.

From the physical standpoint, the original Slavs were in all probability somewhat composite, with differences in the type of the skull, as well as in the color of the hair and eyes. They were probably never entirely homogeneous, either culturally or linguistically. This is substantiated by the fact that in the region occupied, evidently from an early period, by the first Slavs there are found different cranial types; and as to complexion, one portion of the Slavs, at the commencement of historical records concerning these people, is spoken of as possessing light hair and eyes, while another portion is said to have been dark in these respects. The remains of hair in the graves support these statements.

There existed also, before the present era, several distinct cultural regions among the old Slavs, for we find in the west, between the Elbe and Veser, other types of graves and with different contents than on the east of the Veser. The former region connects in these respects with that farther south, in central Europe, while the latter is more nearly related to that north of the Black Sea.

The linguistic differentiation was equally of ancient origin, and was undoubtedly favored not merely by regional developments, but also by isolation, migration, contact, mixing with foreign elements, etc. The eventual result of this differentiation in language was that ancient Slavs, who must still be regarded as originally only

[1] Prepared for the Smithsonian Report, under supervision of the author, on the basis of the publication bearing the title Slovanský Svět (The World of the Slavs), 8vo. Prague, 1910, pp. 1–197. Published also in Russian in the Slav encyclopedia, and in translation in several other Slavic languages.

one body, fell into a number of separate parts. At the present time, and even throughout the period covered by history, Slav people as one national unit no longer exist; their place is occupied by a line of more or less related Slavic nations.

The details regarding the causes and progress of the above individualization are problems that are still to a large extent unsolved. It is most probable, however, that the original Slav people, the nucleus of which occupied the region of the rivers Oder and Dnieper, but who already in the prehistoric times were reaching in places to the Elbe, Saal, and Donau, as well as to the Baltic Sea, fell gradually apart into three primary groups. The first of these, to the west of the Veser and the Carpathian Mountains, expanded still farther on toward the west and became a branch of the Elbe, Pomeranian, Polish, Bohemian and Slovak Slavs; the second main branch, whose original territory was most probably somewhere near the Upper Vistula, the Dniester, and the central Donau, moved in the course of time—with the exception of small remnants—to the south of the Carpathian region and into the Balkans, separating secondarily into the subdivisions of the Slovenians, Srbo-Chorvats ("Serbo-Croatians"), and the Bulgarians. The third main branch of the Slavs finally expanded from the lower Dnieper northward to the Gulf of Finland, westward to the Don and Volga, and southward to the Black Sea and Lower Donau, evolving eventually the Russian nation, which, due to various circumstances, became itself in different localities somewhat heteromorphous.

The degree in which various Slav groups differ from each other to-day, while nowhere excessive, is not everywhere alike. Between the Bohemian, for instance, and the Pole there is a greater gap than between the Bohemian and the Slovak, and that between the Velkorus (Great-Russian) and the Pole is also decidedly greater than that between the former and the Malorus (Small-Russian). In consequence of the less well-defined differences, we constantly meet, in literature and elsewhere, with controversies as to which groups of Slavs can be regarded as independent ethnic units or peoples, and which can not be so regarded. Furthermore, these conditions give rise to disputes in the application to the different groups of the terms nation, nationality, stem, branch, race, etc., and, finally, to disputes concerning the number of present Slav nationalities or peoples. There is no agreement in this regard, different classifications depending on different points of view, such as philological, ethnographical, historical, or political; and even from one and the same standpoint, such as the basis of language, different philologists form unlike classifications. In many cases the tendencies at separation and individualization are given more weight than the actual differences, while elsewhere political motives are responsible for the

making of new nationalities of whose existence, and with full right, others will not even hear. It is in consequence of these conditions that the number of separate Slav groups, and hence the entire Slav classification, varies so much with different authors.

The best authenticated division of the Slavs to-day is about as follows:

1. The Russian stem; recently a strong tendency is manifested toward the recognition within this stem of two nationalities, the Great-Russians and the Small-Russians.

2. The Polish stem; united, with the exception of the small group of the Kašub Slavs, about whom it is as yet uncertain whether they form a part of the Poles or a remnant of the former Baltic Slavs.

3. The Lužice-Serbian stem; dividing into an upper and a lower branch.

4. The Bohemian or Čech and Slovak stem; inseparable in Bohemia and in Moravia, but with a tendency toward individualization among the Hungarian Slovaks.

5. The Slovenian stem.

6. The Srbo-Chorvat (Serbian-Croatian) stem, in which political and cultural, but especially religious, conditions have produced a separation into two nationalities, the Servian and the Croatian; and

7. The Bulgarian stem, united. Only in Macedonia is it still undecided whether to consider the indigenous Slavs as Bulgarians or Servians, or perhaps as an independent branch.

The following pages contain brief data concerning the above divisions:

THE RUSI, OR RUSSIANS.

The beginnings of the Russian nation are hidden in antiquity. There are names of tribes in the works of the old historians, some of which evidently belong to the old Russians, but as yet it is not known positively which can be safely so regarded.

In the fourth century A. D. there appear some hazy notices of the great tribe of Anti. Under this name, it is now known, were comprised the southern Russians of the territory between the lower Donau and the Don; but later this tribal name disappears.

Some misty mention concerning the Russians exist also in the Arabic notes dating from the tenth century. But it is first from the work of Constantine Porfirogennetes, and especially from the famous first Kiev record, preserved from the beginning of the twelfth century, that we learn that toward the end of the first millenium of our era there lived in what is to-day European Russia, a whole series of Slav tribes existing as more or less independent units. The Kiev record mentions 12 such tribes and at the same time gives for the first time to all these people the collective name of Rusi.

How the term "Rusi" arose is still doubtful, but whatever may have been its origin, it is certain that the term was applied foremost to the Kiev center of the population. It was in Kiev, also, that the first Russian state was founded. The name extended thence over broader territory and eventually covered even some tribes that were of a different ethnic origin.

The eastern part of the Russian territory at this time, however, is not one of the parts originally occupied by the Russian people, but is a territory that was colonized by them after other settlers. Similar colonization also progressed from an early period toward the northwest among the Baltic tribes and toward the north and northeast among the Finns.

In the west and southwest, Russian spread was restricted by the presence of the solid body of the Poles; and in the south it was interfered with from early periods of our era by various invasions and migrations of foreign peoples. Into this region, bordering on the Black Sea, came in the third to fourth century the Goths and Heruls; in 376 it was traversed by the Hunns; in 482 by the Volga Bulgarians; before the year 557 by the Avars; in about the middle of the seventh century by the Chazars; and during the ninth century it was occupied for a time by the Uralian Magyars, on their way from the Volga to the Donau.

These invasions, however, only interrupted and delayed the Russian colonization of these more southern regions. Toward the end of the tenth century the tendency southward of the Rusi is more marked than ever, but it becomes again interrupted by the advent of farther eastern hordes, principally Turkish, resulting in long years of wars. During the thirteenth century follows the Tatar invasion, and the victory of the Tatars in 1224 results in a devastation and depopulation of a large part of southern Russia.

The effect of these attacks on the Russian people was deep and lasting. On one hand they detained for a long time their advance southward and westward, and on the other hand they resulted in a counter pressure of the ever increasing Russians against the non-Russian tribes of the northwest and north, with a gradual occupation of piece after piece of territory formerly belonging to peoples of different origin.

During this period also an important political transformation took place within the Russian nation itself. The old tribal system gradually disappeared, giving place to fewer territorial political units, from which eventually arose the three great divisions of the Russians, differing somewhat in tongue, in habits, and occasionally in politics.

These branches were the Velkorusi, the Malorusi, and Bielorusi. Corresponding to these divisions, there arose also during this period the territorial names of Mala Rus (Small Russia), Bila Rus (White

Russia), and Velika Rus (Great Russia). The Malorusi branch remained apparently the purest linguistically. But notwithstanding their differences, these three branches continued as parts of one greater nation, bound together by all that was most important in their existence.

The further development of the Russian people belongs to well-known history. They have not advanced any toward the southwest and west, due to the presence of other solid and strong ethnic units, especially the Poles; but they have progressed greatly toward the north and especially toward the southeast and east. The colonization southward and eastward dates particularly from the fifteenth century, and especially from the time of Peter the Great. From then on we see an elementary, peaceful, and military advance of the Russians over the territory formerly subdued by the Tatars, culminating in 1783 in the fall of the Krimean Dominion, and extending to regions far beyond the original boundaries of the State. Expansion into Siberia, the population of which to-day is already more than four-fifths Russian, commenced in the sixteenth century.

The total number of Russians existing in 1900 amounted to about 94,000,000; at the present date, judging from the average annual increase of the people, their number must be somewhere about 110,000,000.[1]

The regions at the present day most thickly settled by Russians are the black-earth belt east of Poland, and Small-Russia, the least settled being northern Russia and many parts of Siberia.

The proportion of males and females is, in general, 103.4 females to each 100 males, which is close to the condition among other whites. But the birth rate is very large—48 per thousand; the death rate is also large, amounting, on the average, to about 34 per thousand.

Physically, the Russian people everywhere, barring some limited localities, are predominantly brachycephalic. In complexion the Malorusi are, in general, the darkest, the Bielorusi the most blond. The principal differences are observable, on the whole, between the Velkorusi and the Malorusi, but even these are such that to an outside scientific observer both of these branches must remain parts of the same great Russian stem of people.

THE POLACI OR POLES.

The Poles constitute the principal western branch of the Slavs, and of them alone is it possible to say that from immemorial times

[1] In these numbers the Velkorusi are represented by about 67 per cent, the Malorusi by about 27 per cent, and the Bielorusi by about 7 per cent. The Kozaci (Cossack), who are partly of Velkorus and partly of Malorus origin, but who in the course of time have acquired many habits differing from those of ordinary Russians, count, approximately, 3,500,000.

they have occupied the same territory, which is located between the Oder, the Carpathians, and the Baltic. They were always situated centrally as regards the other Slav tribes, and the Polish philologists are of the opinion that even the language corresponds to this central position of the people.

But very little is known about the ancient ethnography of present Poland. It is only with the advent of the ninth century that a little light begins to appear concerning these Slavs. The boundaries of Poland, however, were then unsettled, and the nation itself was still composed of a number of tribes or groups; nevertheless, the people were already looked upon as one by the neighboring Slavs and known under the common name of Liachove or Liachi.

Toward the end of the first millenium, the Poles still consisted, as far as known, of at least five tribes. Between 960 and 1025 the tribe of Poles proper (Polane) succeeded in uniting all these groups, and its name extended over the entire resulting unit. The principal incentives toward this unification of the tribes were wars with the Germans, following the subjugation by the latter of the Slavs along the Elbe.

The tenacious struggles with the Germans, thus initiated, continued and exercised a far-reaching influence on the entire internal and external development of the Polish nation. They resulted in a slow retirement of the Poles on the west and in their corresponding expansion toward the north and the east. Disastrous events to the Poles in the thirteenth century were the invasion of the Tatars, and especially the battle of Lehnice, in 1241, which, among other effects, resulted in the tearing apart of Poland and Silesia.

Quite as disastrous as the above, however, were the continued, extensive, and intense efforts at germanization, proceeding from the west. It was due to these combined agencies that in the thirteenth century the Polish nation was almost at the point of destruction. In these extremes, however, there became manifest a great internal reaction among the Poles, directed particularly against the oppressing Germans. This was accompanied by numerous political and other successes of the nation, and finally, in 1410, in a decisive victory of the Poles at the battle of Grunwald over the German Knights, the principal agents of germanization.

The provinces, however, that were meanwhile lost on the west and northwest, could not be regained, and henceforth Polish expansion was directed principally toward Lithuania and toward the east and southeast into Russian territory. The latter eventually encountered the opposition of the Russians, leading to wars and struggles that lasted for centuries, and which were unfavorable to the Poles, resulting, with other circumstances, in the years 1772, 1793, and 1795, in the tri-partition of the Polish State.

These conditions had of course a deleterious effect on the Polish people, and it was only their great inner vitality, coupled with their traditions and with strong hopes for the future, that kept the nation from annihilation, and that eventually again strengthened and unified it to such a degree that its destruction became impossible.

The tendency toward the germanization of Poland, or at least that part of the country under Germany, continues, however, as intense and active as ever.

The total number of the Poles living at the present date is estimated at approximately 19,000,000. Of that number there lived in Russia in 1900, about 8,500,000; in Austria, 4,250,000; in Germany, 3,450,000; and in the United States of America, 1,500,000.

There are still recognizable within the nation a number of territorial or tribal groups differing somewhat dialectically, but ethnically none of these divisions can be constituted into separate units.

Physically, the Poles show especially a close similarity with the Velkorusi (Great-Russians).

THE LUŽICE (LAUSSITZ) SERBS.

From the powerful branch of the Slavs who centuries ago occupied the territory along the central and lower Elbe there remains to-day only an insignificant body of the so-called Serbians in the Upper and the Lower Lužice.

The Elbe Slavs, at the time from which we have the first historical notices concerning them, that is, in the ninth to the tenth century A. D., consisted of three large groups. From the time of the first records these groups were in constant and intense struggle against two powerful agencies, the Germans and the Roman hierarchy. The inevitable result was that they fell before such odds and became germanized.

From the fifteenth century onward we find only scattered groups of the Elbe Slavs. The more northern examples of these disappear gradually one after another, and the only remnants surviving to this day are the "Laussitz" Serbs, settled near the northern boundary of Bohemia. The cause of the survival of this remnant was, besides other circumstances, the fact that Lužice belonged for a long time to the Bohemian crown. The numbers of the "Lužičani" are, however, steadily diminishing by absorption.

According to the German statistics of 1900, there were still living in Laussitz 93,032 "Serbs," who spoke nothing but their own language. According to other estimates the total number of these "Serbs" at that date was between 150,000 and 160,000 individuals. In 1910 the estimate was 20,000 less. As the people are surrounded by Germans, their complete assimilation with that people can only be a matter of a relatively short time.

An interesting fact is that emigrated Lužice Serbs have founded a number of settlements in the United States, especially in Texas, as, for example, Serbin, West-Yewa, Warda, Burleson.

The language of the upper and lower branches of these peoples, as mentioned above, differed to such an extent that the two must be regarded as distinct dialects.

THE BOHEMIANS (ČECHS) AND SLOVAKS.

The Bohemians and Slovaks, also, are derived from the western body of the Slavs. The Slovaks can in general be regarded as a part of the same ethnic group, although considerably separated by various conditions. Both parts arose from a common center somewhere near that of the Poles and that of the Elbe Slavs, to the north of the Sudet Mountains, reaching, perhaps, into Moravia.

The Bohemians and Slovaks came to their present abodes from the north possibly in one, possibly in separate ways. Historical data concerning these facts there are none, but some light on them begins to rise on the basis of archeological researches. According to the latter investigations both branches had settled their respective territories before the latter half of the first millenium B. C., and hence they can well be regarded as autochthonous in their countries.

Linguistic relations show clearly that both the Bohemians and the Slovaks belong to the same stem as the Poles, the Lužician Serbs and the Elbe Slavs, and that they expanded in connection with these.

Historical data concerning the Bohemians begins in the seventh century. At that time these people occupied a more extensive territory than they do to-day, reaching in places into what is now Bavaria and on the south to the Donau. They also extended farther than they now do into ancient Pannonia (Hungary), and the Slovaks occupied a large portion of the latter country, connecting in the south with other Slavs.

As all the other Slavic branches, so also the Bohemians were at the beginning separated into a number of more or less distinct groups. Among these the Čechové (Čechs) exceled in number and power, and, as with the Polane in Poland, the name of the group eventually became extended over all the other subdivisions, barring the Slovaks. In the ninth and tenth centuries the word Čechové or Češi was already used in the larger sense, embracing the whole people. The territorial term Bohemi was in like sense employed even earlier.

The naturally highly favorable and protected situation of the center of the Bohemians resulted in a rapid and auspicious development of the people, and had it not been for some of its rulers with their foreign sympathies, the nation would have played an even more important rôle than it did among the Slavs and would doubtless occupy to-day a different political position.

The most detrimental procedure of some of these rulers was the colonization of parts of Bohemia and Moravia by Germans. This colonization and contemporaneous germanization continued, favored also by the nobility and the clergy, until the fourteenth century, when it was checked effectually for a time by a revulsion of the people, manifested in part in the wonder-inspiring Husite wars. The process of Germanization at that time extended even to the Slovaks in northern Hungary.

The Husite (after Jan Hus, the martyred reformer and patriot) wars were conducted victoriously mainly under the banner of religion, but at the same time it was a struggle for Bohemian nationality and against the invading Germans. As a result of these wars, the Bohemian language again became the official language in Bohemia, Moravia, and Silesia, and there was a general national rejuvenation.

The German waves, however, could be stayed only for a time, and in the sixteenth and particularly the seventeenth centuries their effect again became manifest.

The early part of the seventeenth century (1620) marks the disastrous battle of Bílá Hora, near Prague. Then followed a period of intense religious oppression, confiscation of property, exile of tens of thousands of the best families, and the repeated destructive invasions of the Thirty Years' War, all of which left the Bohemian element greatly reduced in numbers and on the verge of exhaustion. Then came further German colonization and more germanization.

Toward the end of the eighteenth and at the beginning of the nineteenth century it seemed as if the Čechs were to follow the fate of the Elbe Slavs. Instead of this, however, there became manifest a marked and gradually growing reawakening of the national spirit, attended with a purification of the language, and not merely a successful opposition to further germanization, but a slow and continuous gain of old positions in all directions.

A century ago it seemed as if the nation was doomed. To-day it stands among the most cultured and united, as well as intellectually and industrially productive, in the compact strength of nearly 7,000,000, exclusive of the 2,000,000 Slovaks in Hungary. The history of the people from the fourteenth century to date reads like a fable.

The Slovaks are subject to forcible magyarization which, with their environment, has retarded their progress in all directions.

The total number of Bohemian Slovak people in existence is estimated at somewhat over 9,000,000 individuals, and of that number at least 300,000 Bohemians and 500,000 Slovaks live in the United States.

There is a considerable difference between the Bohemians and Slovaks in education. Among the former the percentage of those able to read and write exceeds even that among the Germans, and is

the highest (for larger groups) in Europe; among the Slovaks, due to the highly unfavorable local conditions, the percentage of analphabets ranges from 32 to 42 per cent.

As to occupations, there are among the Bohemians 43 per cent devoted to agriculture, 36.5 per cent to industry, and 9.3 per cent to transportation, while 11.1 per cent are in civil service.

Tribal differentiation among the Bohemians has to a very large extent disappeared. Highly interesting remnants of tribal differences, however, are met with in numerous localities, as indicated by dress and certain habits of the people, and also in a few places by the dialect. There are recognized three strains of these dialectic shades, but none is of any special importance.

Physically, the Bohemians are characterized by a good stature (average of men 169.2, of women 157.3 centimeters) with a brachycephalic skull of, on the average, a considerable capacity (Weissbach). They are somewhat predominantly of a darker type, but blond and mixed individuals and especially those with lighter-colored eyes are quite common. It is evident that the type is not strictly homogeneous, but the differences are very largely only individual.

THE SLOVENIANS.

The Slovenians are the northwestern portion of the southern Slavs and a remnant of a once powerful branch known at Slovieni, which at the beginning of the Middle Ages spread over the territory between the Pannonian bend of the Donau and the Adriatic Sea, reaching at the same time far into the Alpine regions.

Nothing is known historically as to the date and circumstances of the first appearance of the Slovenians in this territory. It seems that their penetration there had commenced at or even before the beginning of the Christian era, but definite proofs of this supposition are still lacking. What is certain is, that from the sixth century onward the territory became filled with Slavs, and in the year 600 we read that they were then imperiling Italy. They occupied what are now the southern half of Lower Austria, Styria, Carinthia, Gorizia, and Carniola, as well as a part of Tyrol and Upper Austria. This distribution is authenticated by the topographical and historical nomenclature as well as by a number of direct historical notes regarding these Slav settlements.

In the earlier part of their history, however, the Slovenians were subjugated by the Avars. They were liberated from this yoke during the first half of the seventh century, but during the eighth century were overcome in turn by the Bavarians, who initiated a progressive and long-lasting germanization. Still later, after the invasion of the Magyars, germanization was rapidly replaced by

magyarization, the cause of both being the preponderance in numbers and power of the Germans on one side and of the Magyars on the other, over the Slovenians.

To-day the Slovenian territory is limited to Carniola, the northern part of Istria, Gorizia, and parts of Styria and Carinthia, with small regions in northeastern Italy and in western Hungary.

The total number of Slovenians is now only about 1,500,000, of whom about 100,000 live in the United States.

CROATIANS AND SERBIANS.

Croatians and Serbians arose, with the Slovenians and the Bulgarians, from the southern main Slav stem or division. They formed at the beginning a linguistic unit, which did not become separated into two parts or two nationalities until during historic times. Both of these units, although aware of their close relation, to-day defend a nationalistic individuality.

The conditions leading to the separation of the two branches were, as elsewhere, territorial, tribal, and dialectic differences. The original body at first consisted of a series of tribes belonging to one linguistic group, but dialectically slightly differentiated, which expanded from their more northern cradle, near the Carpathians, toward the Donau and beyond that to the Dráva, Sáva, and farther on to the Balkans. It was only in the latter region, with the Balkan Mountains presenting boundaries difficult to traverse and hence impeding communication, that some of the subdivisions became separated and further differentiated, leading eventually to the present grouping into two nationalities.

In the northwest and west the original segregation of the tribes gradually gave rise to the Croatians, while the more eastern group became the Servians. The Croatians led an independent political existence from probably as early as the seventh century until 1102, when the Croatian Kingdom became attached to Hungary, with which, in 1526, it became a part of Austria-Hungary. The Servians were organized as a separate political body somewhat later, between the 10th and 11th centuries, and retained their independence until after the battle with the Turks on Kosovo Pole, in 1389, after which their territory was made a part of the Ottoman Empire.

The Turkish subjection of the Servians resulted in the emigration of masses of the Servians and also of the Croatians northward into southern Hungary and into other parts of the southern portion of the Austrian States.

At the present day the Croatians are settled entirely within boundaries of the Austrian Empire. They occupy parts of the coast land and Istria, portions of Dalmatia and Bosnia, and entire

Croatia, in addition to which they are found in numerous localities in southern Hungary and in Slavonia.

The nucleus of the Servians rests in Servia and Montenegro, whence they extend to Bosnia and Herzegovina, now annexed to Austria-Hungary, to parts of Dalmatia, Slavonia, southern Hungary, and to northwestern Albania and Macedonia.

Separate statistics of the two nationalities are not available. Together they numbered in 1900 approximately 9,000,000 individuals, of whom somewhat more than 3,500,000 were in Austria-Hungary, a little less than 2,000,000 in Bosnia and Herzegovina, 350,000 in Montenegro, 2,300,000 in Servia, 400,000 in old Servia, Macedonia, and Albania, and about 300,000 in the United States and elsewhere in America.

Both the Servians and Croatians are predominately agricultural people, the percentage of farmers in different localities reaching between 80 and 90 per cent of the population.

As in all the other Slav branches, so among the Servians and Croatians, there exist a number of secondary groups, differing from each other dialectically; but none of these interesting divisions is of great importance.

From the anthropological standpoint the Servians, as well as the Croations, are predominantly of a darker complexion and are strongly brachycephalic.

THE BULGARIANS.

The last Slav nation which resulted from the differentiation within the southern stem or main division of the Slavs, are the Bulgarians, who to-day live almost exclusively on the Balkan Peninsula.

As was the case with the other branches of the southern Slavic division, so the Bulgarians had their cradle much farther to the north, somewhere above the Carpathian Mountains, in the neighborhood of the Russians. From these regions they had already begun as early as the third to the fifth century A. D. to penetrate toward the lower Donau, and in the sixth century they reached the Balkans. At this time and even during the seventh and eighth centuries of our era, the people consisted of a considerable number of separate groups more or less loosely united.

In the year 679 there arrived in the region occupied by these groups a body of Volga Bulgars, of Turkish descent. These invaders subjected the nearest of the aforementioned groups, united them, and subsequently the union extended to the remaining Slavs in the central part of the peninsula.

The Volga Bulgars very soon became assimilated into the Slav element and disappeared as a separate body, but they left their name to the united new people. In general, it may be said that the Bulgars

were always Slavs, although they suffered a considerable admixture of foreign elements.

The Bulgarian Kingdom during the ninth and tenth centuries had spread over a large territory. It carried on numerous wars with the Byzantines on one hand and the Servians on the other, until the time of the Turkish invasion. In 1396 the battle of Nikopole resulted in the forcible submission of Bulgaria to the Turks, a submission lasting until 1878, when, with the help of Russia, the country again gained a limited freedom. In 1885 Bulgaria succeeded in regaining a large part of Roumelia; and recently, on the occasion of the annexation by Austria-Hungary of Bosnia and Herzegovina, and that of political disorders in Turkey, Bulgaria again attained complete independence. To-day it is the strongest and most progressive nation of the Balkans.

Throughout its history, but especially during and even after the Turkish occupation, Bulgaria has witnessed many internal movements of population. At present the restlessness is confined to the Bulgarians of Macedonia.

The total number of Bulgarians at the present day exceeds 5,000,000. Of these approximately 3,000,0000 reside in Bulgaria proper, 1,200,000 in Macedonia; 600,000 in other parts of the Balkan Peninsula and Turkey, 180,000 in Russia, and about 100,000 in Roumania and Dobrudža. In America, particularly in the United States, the Bulgarians are represented by only small numbers.

Exclusive of groups belonging to other nationalities which are settled in Bulgaria, the Bulgarians themselves show an internal differentiation into three principal subdivisions, differing somewhat dialectically and in other respects. None of these divisions, however, is sufficiently apart from the body of the people to make possible any actual separation. Besides this, there are met with in Bulgaria (as in Servia) many local names of groups, with no, or but very little, ethnic significance.

From the anthropological standpoint, according to the most reliable data, the Bulgarians are somewhat heterogeneous. The typical Bulgarian is of medium height (166.5 centimeters for men and 156.7 centimeters for women), and predominantly dark (50 per cent dark, 5 per cent light, 45 per cent mixed complexion). The head is predominantly mesocephalic, with a rising proportion of brachycephaly in the southwestern part of Bulgaria and in southern Macedonia. Dolichocephalic forms appear in parts of southern Bulgaria.

Regarding the Slavs in Macedonia, there is still a difference of opinion as to whether they are nearer the Bulgarians or the Servians, or whether they constitute an independent Macedonian Slav people. As the matter is complicated by politics, a continuation of the discussion must be expected. There is no doubt that a large part of the

Macedonian Slavs feel and proclaim themselves to be Bulgarians, and also that the dialects of the people are nearer the Bulgarian language than the Servian, with the exception of the northern part of the region, which in turn is more Servian.

CONCLUDING REMARKS.

The Slavs are of central European origin and of the same descent as other Indo-European or Aryan whites, though in some regions they have in the course of time become mixed with other elements.

The total number of Slavs at the close of the year 1910 may be estimated at about 156,000,000 to 157,000,000. In this number the Russians are represented by nearly 70 per cent, the Poles by 13 per cent, the Bohemians and Slovaks by a little over 7 per cent, the Servians and Croatians by a little less than 7 per cent, the Bulgarians by about 3.7 per cent, the Slovenians by a little over 1 per cent, and the Lužice (Laussitz) Serbs by a little over 0.1 per cent.

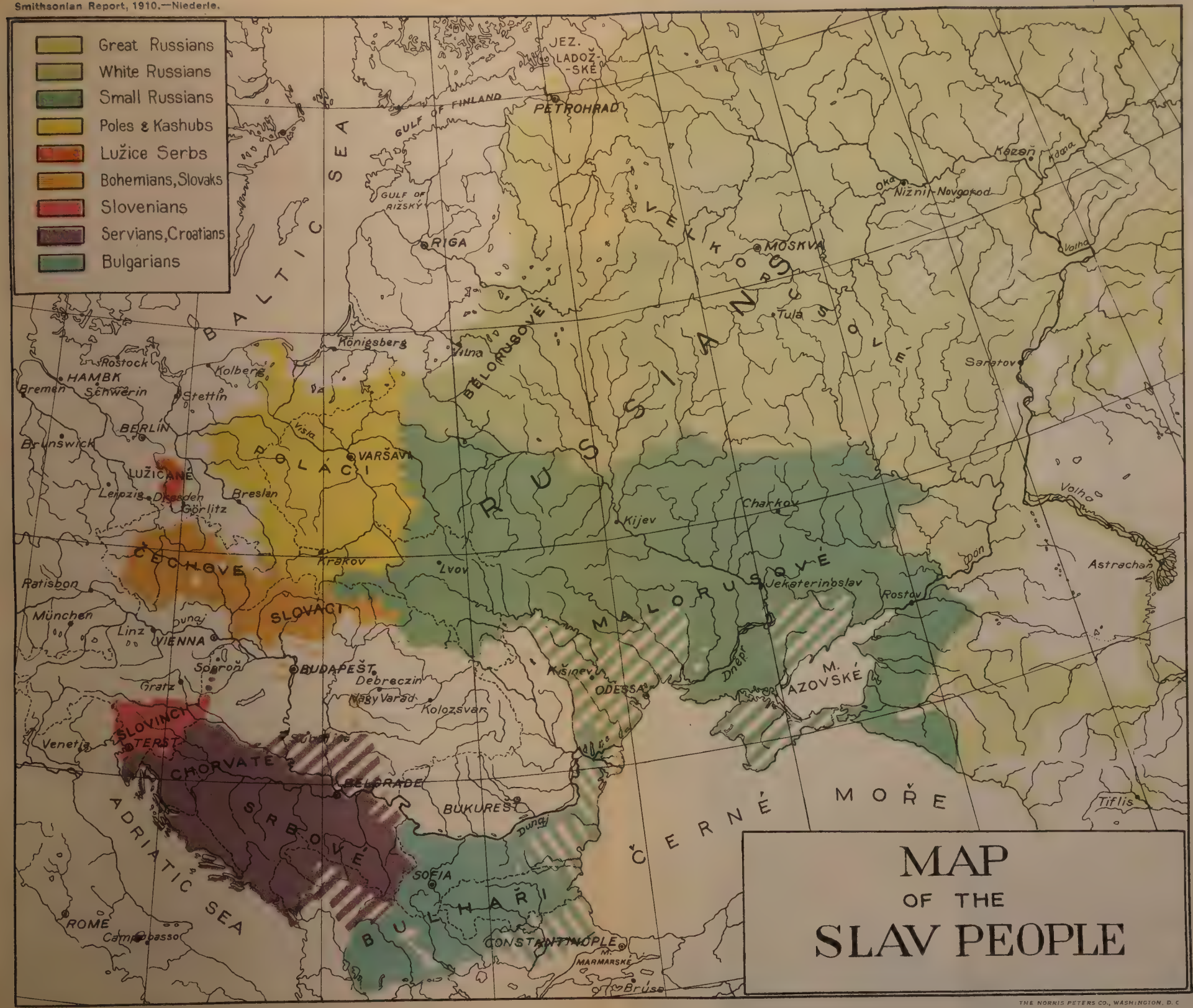
The stock is in general a naturally well-preserved and sturdy one. The mean annual increase in numbers amounts to about 1.4 per cent.

Anthropologically, the Slavs are characterized by a mostly rounded head, good cranial capacity, medium stature, and a good physical development. In complexion they range from brunette to blond, the former predominating among the southern Slavs and among the Malorussians, while blonds are more numerous among the northern parts of the stock, and especially among the Bielorussians.

Culturally, numerous parts of the people are as yet more or less retarded, due not to any want of natural abilities, but to lack of facilities of education, and to oppression.

Those Slavs who emigrate, particularly to North America, become generally (with the exception of a certain percentage of the Slovaks, who return to their families) completely assimilated with the indigenous population within two generations.

NOTE.—Prof. Niederle's work contains many special details which could not well be included in this abstract, due to limit of space, and there is also given an extensive bibliography relating to the different stems and branches of the Slavs, for which the reader must be referred to the original.



MAP OF THE SLAV PEOPLE

THE NORRIS PETERS CO., WASHINGTON, D. C

THE CAVE DWELLINGS OF THE OLD AND NEW WORLDS.

[With 11 plates.]

By J. Walter Fewkes.

In considering many subjects suitable for a presidential address that of "The Cave Dwellings of the Old and New Worlds"[1] has seemed to me timely as illustrating certain aspects of culture history that are only vaguely comprehended by those unfamiliar with our science, and often overlooked by professional anthropologists. The subject enables me to call attention to the intimate connection existing between history and geography, and to lay before you data bearing on the theory that culture similarities in distant lands are due not so much to derivation as to a mental unity on account of which human thoughts are similarly affected by a like environment. This subject also brings into relief significant limitations of the theory that culture development is due wholly to external conditions, while the data here presented show the existence of diversities in culture which have apparently no relation to those conditions.

There is nothing produced by the human mind and hand that reflects individual and racial characters more accurately than man's habitations. It is a far-reaching ethnological law that the house is the most truthful expression of the mind of the inhabitant; natural man in constructing his dwellings must avail himself of the material which is nearest at hand for that purpose.

It is convenient for purposes of study to consider human habitations as arranged in two series which are not necessarily local lines of evolution—houses of wood including those of sticks, bark, grass, hides, and those of stone embracing earth, clay, and the like. Our subject is especially concerned with the origin and development of the latter. The simplest kind of durable house or shelter is the cave, the choice of which for habitation generally leads ultimately into

[1] Presidential address delivered before the Anthropological Society of Washington, April 12, 1910. This address was accompanied by stereopticon views illustrating many of the points presented, which can not be reproduced as illustrations.

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permanent structures. The cave as an element in the history of human habitation is conditioned in its influence by its geographical extension.

You may have noticed that I have spoken of the intimate connection of history and geography, and it may be added that in using the former term I include in it both ethnology and archæology. It seems to me that the time is coming when the science of history will no longer be made up solely of descriptions of past events, even when including within its ken economics and institutions, but will embrace a study of cultural life in its broadest significance. The time is not far distant when the discoveries of the ethnographer will enlarge the scope of history, so that this science will embrace all forms of culture, among all men, both low and high in development. Ethnology is destined to infuse into history a meaning more comprehensive than it has yet had and to bring into sharper relief the relation of cultural life and geographical surroundings.

Human thought, as expressed by material culture, language, and beliefs, is modified to a certain extent by survivals of past environments. In early conditions this modification was strong, but later, when man had obtained greater control over his surroundings, external conditions lost some of their power. The character of primitive habitations is perhaps more influenced by environment than any other product of man's intelligence, but even in them we find surviving traces of former conditions.[1] The effect which the adoption of caves as habitations has had on the construction of buildings within them illustrates this statement. Originally caves were sought out for protection from elements, but in the course of time, possibly from conservatism, man continued to construct buildings in caves and to live in caverns long after necessity for them had ceased. The fact that nothing of man's manufacture is more profoundly modified by environment than his habitation gives to caves or cave dwellings a great importance in the study of the interrelations of history and geography.

The reason that led man originally to seek caves for habitation was a desire for shelter from the elements, but not so much protection for himself as for others—for his offspring. Caves were early used for the hiding away of food and secretion of other property, as sacred images and ceremonial paraphernalia, for burial places, and as chambers for the performance of sacred rites. Their use for habitation was secondary, the primary motive being mainly altruistic, the same as that which leads the insect, bird, and mammal to make their nests.

[1] The effect of migration and retention of cultural survivals of former environments should not be overlooked, although as time passes it becomes more and more obscure.

As one of the few crafts man shares with animals is the building habit, it is natural for us, on the very threshold of the subject, to consider the influence of environment on lower intelligences as expressed by insects, birds, mammals; or perhaps it might be better to say the study of the habitations of lower animals should go hand in hand with those of natural man.[1] We are immediately informed that the bird acts not from reason but from inherited habit or instinct. The first swallows which built under the eaves of a house or in a chimney of the same surely had no inherited instinct to guide them. This choice was certainly not due to former teaching in the site that has been inherited, but to an independent use of mind which recognized the advantage of a new environmental condition. It does not seem unreasonable to suppose that the birds that first built their nests under overhanging cliffs did so for the same reason that men built in similar places. Both bird and man saw that the caves were advantageous for shelter and built accordingly.

The cave swallow builds its nest of available material, as stones, clay, and twigs. I possess a photograph showing one of these animal cliff dwellings which indicates how close a parallelism can be traced in the choice of a site and material for a building by animals and man as determined by their environment—a most fascinating subject to which I can give only brief mention at this time. The outcome of the comparison is that there appears to be a general psychic law showing identity of thought among animals and men in the construction of buildings or nests where available material and geographical conditions are the same.

Life in caves passes naturally into one in permanent houses of stone or clay. If we follow Ratsel in his conclusion that "the germ of stone architecture" arose from "the habit of dwelling in caves widely spread in primitive times and not yet obsolete," then the geographical distribution of caves has largely determined the sites of monument development and consequently of civilization. The effect of stone buildings made by one generation on development of the culture in the next and subsequent generations is very considerable, and the perpetual existence of monuments is a continual

[1] This great "untilled field of comparative psychology," as pointed out by a reviewer in The Atheneum (Aug. 20, 1910), of Dr. H. C. McCook's Ant Communities and how they are Governed, "will be extended from the primitive human type to the conceptions of other animals, but zoologists must find the materials." Although somewhat foreign to my subject the following comment by Dr. Cook on the discovery of a story in an ant's nest 8 feet deep is instructive:

"Those who are curious in such comparisons might find grounds here for a striking parallel between the achievement of an ant three-eights of an inch high (long) and of a man 176 times as high (5½ feet). Were we to reckon on a proportionate rate of progress between the two on the basis of height, our man would have to be credited with a storied structure 1,408 feet deep."

stimulus acting on the mind to interest it in past history and create a pride in former achievements. It is self-evident that a race, each generation of which builds houses of perishable material, leaves little evidence of its past history, and whenever the creations of one generation fall into decay in the next there remains nothing to which tradition may point with pride. If the past adds nothing to the present a race progress is not possible. Stone habitations become monuments and endure, not only serving as an inspiration for new endeavor but also securing lasting models for future generations. It is on these accounts that the limits of artificial cave habitations are almost always the same as those of higher human culture, historic and prehistoric.[1]

Caves showing evidences of habitations are widely distributed geographically. Beginning with China, a belt of cave dwellings extends across India to Asia Minor and Arabia, following both shores of the Mediterranean, continuing into the Canary Islands, the West Indies, Mexico, North and South America. Wherever geological conditions furnish a rock that can readily be worked into suitable caves there are generally found ruins of stone buildings, and where these exist there we are almost sure to see other evidences of past culture.

Two lines of architectural evolution reach back to the cave as the original form: (1) Growth of a building within a natural cave, and (2) evolution of a building from an artificial cave. While natural caves must theoretically have formed the earlier shelter, we find, when the character of the rock permits, that artificial caves were constructed almost contemporaneously with them.

The use of unmodified natural caverns for shelter can not be considered at length at this time, but in passing it may be pointed out that, while not limited to any one geographical location or climatic condition, they are necessarily found under certain geological conditions. Existing historical, legendary, and archeological accounts[2] of human habitations in natural caves of Europe are very numerous, but no extensive literature exists on the natural cave man of Asia, Africa, and America. The association of human remains with those of extinct animals in European caves carries the antiquity of man into late geological formations. The limited observations on New World caves rather than the poverty of the subject makes it difficult, almost impossible in fact, to institute an adequate comparison of the culture or relative age of the natural cave man of America and Europe.

In order to show how little work has been done on this subject in America, let me call your attention to one of many examples. At the

[1] Higher culture without permanent habitations or sacred edifices is almost inconceivable.

[2] Wm. Boyd Dawkins, Cave Hunting: Researches on the evidence of caves respecting the early inhabitants of Europe, London, 1874.

close of the fifteenth century, when Columbus discovered America, there were cave dwellers in certain regions of the West Indies, which were mentioned in the writings of early historians. The people who inhabited the greater part of these islands were dwellers in the open and had attained a considerable cultural elevation as shown in the polished stone objects called "collars" and three-pointed idols or zemis. The germ of this culture came from South America. In addition there were settlements of Caribs who had migrated northward from South America along the Lesser Antilles as far as Vieques Island and the eastern shore of Porto Rico. It would appear from history that there were at least three distinct stocks, indicating three kinds of culture, in the West Indies at the epoch of discovery. The first and most primitive of these three were the cave dwellers, remnants of an aboriginal people once spread all over the West Indies, but at that time inhabiting the western ends of Cuba and Haiti. They were known to early writers as the Guanahatibibes,[1] and were said to have been low in cultural development, possessing a characteristic idiom, their livelihood being obtained by fishing, hunting, or gathering wild fruits or roots. These apparently had not yet become an agricultural people, and had no knowledge of how to prepare cassava from the poisonous root of the yuca.

The existence of this race of natural cave dwellers in the West Indies has long been known through legends extant since the time of Columbus. Roman Pane, the oldest folklorist of the American Indians, in one of the legends of the natives of Haiti refers incidentally to their former life in caves—a legend which was no doubt founded on historical fact. It is known that some of the Haitian caves were inhabited by man at the discovery of the island, and we may infer that these troglodytes were survivals of an antecedent epoch, referred to in the legend, when the aborigines of the island were cave dwellers.

While, as seen from the above remarks, evidence drawn from folklore supports history, the archeological verification has yet to be gathered. Our knowledge of the character of the West Indian cave culture is fragmentary and can be greatly enlarged by systematic excavation of the caves of Cuba, Haiti, and Porto Rico. Skeletal remains which may be referred to the cave men of Cuba have been investigated by several Cuban anthropologists, who have regarded

[1] In western Cuba; their province in Haiti was called Gaucarima. The structures called "cacimbas" in the Isle of Pines and elsewhere in western Cuba may have been made by the prehistoric cave dwellers of Cuba. These cacimbas are large earthern jars, apparently fashioned and baked in place, filling a hole 6 feet deep, with rim level with the surface of the ground. Additional study is necessary to determine their age and use.

NOTE.—A careful study of 25 of these cacimbas in May, 1911, showed that while they are almost universally shaped like jars their walls were not of clay baked in place, as I had been informed, but made of masonry plastered or excavated in solid rock. A thin layer of tar on their sides and floors seems to indicate they were used as receptacles for turpentine or tar. Their construction as well as their use is still doubtful.—J. W. F.

them as among the oldest in America. A comparison of the culture of these cave men with those of Europe would be very instructive, but it is manifestly impossible considering our limited knowledge of the former. Here is an opportunity for the study of cave men at our very door, practically within our domain, which offers a most fascinating field rich with harvest to our historians, folklorists, and archæologists.[1]

A comparison of artificial caves and buildings constructed in natural caverns in the Old and New Worlds is much easier to make than that of the natural caves of the two hemispheres on account of the abundant known material. Both America and the Old World have an extensive literature of artificial caves used for habitations or natural caves sheltering buildings of size. Historically speaking we have little information regarding the life of man in artificial caves or in buildings in natural caverns in America, but this lack may be supplemented by the contributions of archæology, and our knowledge may be enriched by a study of the folklore[2] of the Pueblo Indians.

In addition to legends capable of verification by archæology, the Hopi also have others less definite which, although vague, are still as worthy of belief as those dealing with the period of history, if taken symbolically. Pueblo legends all agree that the human race orginated in an underworld and climbed to the surface, where it now dwells, through an opening which the Hopi call "the Sipapû." A comparative study of these stories among different pueblos reveals the fact that this emergence opening does not always have the same position, creating doubts as to the authenticity of the location of Sipapû and raising a suspicion that geographically it is not to be taken literally, but varies with the clan or larger group. Moreover, the legend, greatly obscured by esoteric and symbolic interpretation, may indicate a local prehistoric event.[3] It is usual to interpret "the Sipapû" as the original orifice of emergence common to all members of the human race, but it is worth while to consider whether it does not sometimes refer to the passage from a previous culture. If we interpret the underworld[4] to be a prehistoric underground habitation, we can bring several facts of archeology and ethnology to its support.

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[1] Mr. J. N. B. Hewitt has also called my attention to the following legend on an old map by De l'Isle near what is now Williamsport, Pa.: "les Tionontatecaga qui habitent dans des cavernes pour se deffendre de la grande chaleur."

[2] The legends of the life of some of the Hopi clans in the cliff houses of the Navaho National Monument, possibly vague as to the exact site of these cliff dwellings, are as vivid to them as their life in any historic ruin like Awatobi. These legends do not always refer to historic times, but often indicate the individual cliff dwelling once inhabited by specific clans, as those in the Chelly Canyon, which comes well into the historic period, although not recorded in historical documents.

[3] Or the present conception of a universal Sipapû may have been a generalization from a purely local historical account of the passage of culture from the caves to the open.

[4] The "pit dwelling," or as they are sometimes designated "underground habitations," referred to throughout this lecture are allied to but not identical with cliff dwellings and pueblos. Cliff dwelings are of two kinds: Cavate rooms or those artifically excavated in

There can hardly be a doubt that the remote ancestor of the cliff pueblo was an inhabitant of a natural cave, and that the construction of an artificial cave and a pit dwelling was also early in time. As man developed into a mason[1] he outgrew the narrow bounds of a cavern and, erecting buildings in front of his artificial caves, relegated the latter to storage or ceremonial purposes, just as in certain places in Asia Minor caves are granaries and have houses in front of them which are inhabited.

Knowing as we do that early man in Europe inhabited natural caves, the question naturally arises why there is a total absence in Europe of large villages like the great cliff houses of Arizona and Colorado. This is partly due to the limited size of the caves, for there are no European caverns suitable or ample enough to contain large villages. The step from the cave dwelling to the construction of stone buildings in the open was an early one and was probably brought about by overcrowding. After the population of the cave had outgrown its limits two remedies were possible for accommodation of the increase. Crowded out of caves by enlargement in numbers, man was forced either to build rooms in front of the caves he had excavated or, cutting free from the cliffs, to construct an independent house in the plain or on the mesa.

It is not unlikely, also, that in some instances he first inhabited pit dwellings or habitations underground. Such simple dwellings as these were not unlike some ancient aboriginal habitations of California or the earth lodges in the plains east of the plateau region. If we regard the so-called cavate lodges and the pit dwellings as primordial dwellings, much that is incomprehensible in cliff-dwelling architecture can be readily explained.

Although numerous examples of pit dwellings in the Southwest may be mentioned, the Old Caves near Flagstaff, Ariz., are among the best representatives. A visitor on approaching one of these habitations first observes on top of an elevation broken down walls of one-storied rooms forming a cluster, the ground plan of which would not be unlike a checker board.[2] These walls, constructed of lava blocks, gave to this cluster of rooms the appearance of a small one-storied

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the walls of cliffs and cliff houses, or cliff pueblos, houses or pueblos with walls built in natural caves. There is of course no strict line of demarkation between these different types and some settlements are composites of two or more kinds of dwellings. The pit dwellings belong to a distinct type of southwestern ruins, represented in cliff dwellings and pueblos by the substerranean sacred room or kiva.

[1] The training of primitive man into a mason was rapid wherever rocks about him could be worked with rude implements. The excavations of caves led to stone buildings. No better illustration of the dependence of architecture on the character of rock can be found than by a comparison of the prehistoric monuments of Cuba and Yucatan. Easily worked rocks of the latter country made possible the magnificent temples that have been the wonder of archæologists.

[2] Similar walls forming an inclosure into which open the doorways of cave dwellings are figured in a cut of Madeba, by Libbey and Hoskins, the Jordan Valley and Petra, vol. 1.

pueblo, but on entering the inclosures one sees in the middle of each floor a vertical entrance through which the the inhabitants descended to a subterranean chamber, excavated in the solid rock. This underground chamber was entered from lateral rooms by doorways which also had been excavated in the lava conglomerate. From the plastering on the walls of these rooms it is evident that they were not used simply for storage, but served for habitations and were true pit dwellings.[1] Let us consider still another example of these early subterranean houses with vertical entrances inhabited by the aborigines of Arizona. Certain ruins on the Little Colorado have underground rooms that indicate even better than the Old Caves the character of pit-room culture antedating the free buildings called pueblos. Some of the best of these exist in considerable numbers in a cluster of ruins near the Black Falls of the Little Colorado. These rooms are underground, single, multiple, or arranged in rows, being generally found in the shelter of a low outcropping rock formation sometimes occurring at the base of a low cliff on top of which is a pueblo ruin. Their form is generally round or they have rounded corners, one side being the cliff walls. A row of underground rooms of this type morphologically resembles a series of subterranean kivas. There is nothing to show that they were specialized for ceremonial purposes, but they are believed to belong to the type of subterranean dwelling called a "pit room," of which the kiva is the modern survival.

Some of the Armenian cave dwellings belong to that type of cavate house characterized by a vertical entrance. In the writings of Xenophon there is said to occur the following reference to these troglodytes visited by Polycrates and certain others of his command: "Their houses were underground, with entrances like that of a well, though they were spacious below. The entrances for the animals were dug out, but the men descended by means of ladders. In these houses there were goats, cows, chickens, and the young of the same. The animals were fed on hay inside the houses, which also held a store of wheat, barley, vegetables, and barley-beer in great vessels."

As in certain Southwestern cavate houses some of the cave villages of Asia Minor had a series of houses above ground which were occupied, and another series, subterranean in position, entered by tunnels, and advantageously situated for protection from foes. The use of the underground rooms as places of refuge, those in the open serving as habitations, may furnish a clue to the use of cavate rooms under or behind houses in prehistoric New Mexico and Arizona.

The Asiatic excavated rooms were used by their inhabitants for protection against Ibrahim Pasha, who, with an Egyptian army in a

[1] I recognize in these pit rooms the precursors of the subterranean kivas, the vertical entrance representing a hatchway.

campaign against Turkey, came to a town of this character in Asia Minor. The people fled to their subterranean rooms, closing the entrance behind them by rolling great stones over the doorways,[1] so that the Egyptian soldiers could not force their way into these retreats. When the latter were sorely in need of water and lowered buckets to draw it up from the wells, it is said the people underground cut the ropes, causing the soldiers to withdraw.

Dr. Ellsworth Huntington, in an interesting account of his visit to certain Druse caves in Syria, published in Harper's Magazine, for April, 1910, has shown how this was possible. It appears that these caves were safe retreats in time of danger, being in communication with houses above. He found in them remains of tanks, from which water could be drawn by those in rooms above. It would not be possible to obtain water if there were hostile people in the caves below near the tanks.

The most instructive résumé of the dwellings of the aborigines of North America has been written by Herr Sarfert,[2] who has considered many points of interest to the student of subterranean or cave habitations. It would seem from his studies that underground habitations had a wide distribution in the New World in prehistoric times, and that there was a line of such, interrupted at intervals, extending from the Aleutian Islands along the west coast of North America into Central America. The relation of the underground ceremonial room in California and the kiva in the pueblo region is not the least of many interesting suggestions in Herr Sarfert's article.

Cavate habitations in cliffs on Oak Creek, a tributary of the Verde, Ariz., correspond with caves used by Guanches for ceremonies and burials in the Canaries. Many similar examples from the Old and New Worlds might have been chosen, some with buildings before them, others destitute of the same. In many instances these former habitations have become burial chambers, once deserted by the inhabitants; they were used later as catacombs for the dead. Instances of this secondary use can be found all the way from China to the southwestern part of the United States.

These artificial caves are not confined to Asia and America, but are also abundant in Europe. Many are found in Germany,[3] in France (pls. 1, 2) along the River Loire, where the older cave rooms now serve for storage, and new, occupied dwellings have been erected in front of them.[4] The caves of Dordogne, France, have been studied and their contents figured and described in the magnificent work,

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[1] The method of closing the doorway by rolling a great circular stone before it seems to have been common in the cave habitations of Asia Minor.

[2] Haus and Dorf bei den Eigeborenen Nordamerikas, Archiv f. Anthrop, vol. 25.

[3] See Lambert Karmer, Künstliche Höhlen aus Alter Zeit, Wien, 1903. The examples described are from Germany and America.

[4] I am indebted to Professor Partington, of the National Park Seminary, for the use of the photographs used for plates 1 and 2.

Reliquiae Aquitanicae, by MM. Lartet and Cristy. The Aquitani of Cæsar's time lived in caves, and the caverns of Dordogne were inhabited in the Middle Ages. According to M. Desnoyers, writes Boyd Dawkins:

> In France there are at the present time whole villages, including the church, to be found in the rocks, which are merely caves modified, extended, and altered by the hand of man.

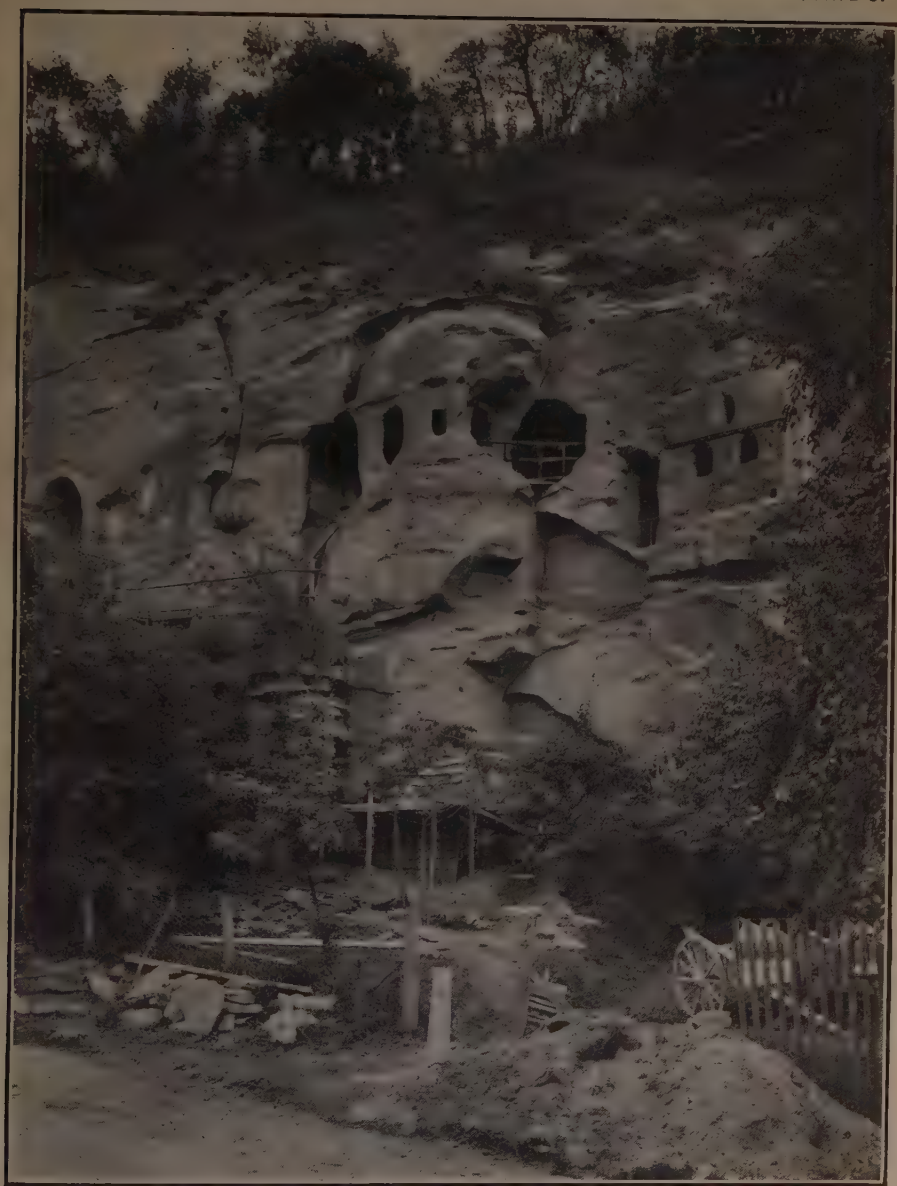
The so-called Heidenlöcher, Pagan holes (pl. 3), at Goldback, overlooking Lake Constance in South Germany, may be taken as typical examples of certain European cave dwellings excavated in the loess formation, recalling those in tufa along the Verde in Arizona. My attention was first called to these interesting caves by H. von Bayer, who has given me an English translation from a German account published in the Ueberlinger Badblatt (Nos. 6 and 7, Aug. 6, 22, 1910), and a short notice published in 1827 in Gustav Schwab's Der Bodensee nebst dem Rheinthal. As these descriptions are too long to quote in my address, I have introduced a condensed account embodying the main features of the two. These caves are excavated in a cliff rising perpendicular from the lake about 7 meters above the water level, and were formerly approached by ladders from a narrow path that once skirted the shore.

> The Heidenlöcher formerly consisted of a series of rooms, chambers, cellars, and niches connected with each other by hallways and stairs, extending for a distance of almost a kilometer * * *. The single rooms are of different sizes and shapes, some have groined arches, or at least the beginning of them with the springers; others have flat ceilings, some have columns, pilasters, architraves, and cornices; others are simple and without ornamentation. In nearly all of them, however, are to be found stone benches, niches, window and door openings with grooves cut out to receive the frames, and even the remains of wooden dowels. In some places in the cliff are to be seen niches and rifts which no doubt are remains of a former cave dwelling.

The present approach (pl. 4, fig. 1) is by stone steps along the face of the cliff, the former stairs being badly disintegrated. There are now seven caves, a large number having been destroyed in 1846–1848, when a road was constructed between Ueberlingen and Ludwigshafen. The first cave, entered by an arched doorway, is 3 meters high and has niches near the entrance. The second cave has two windows open and a chimney. A niche in this opens into a third cave 1.8 meters high and 2 meters wide. The fourth cave (pl. 4, fig. 2), over 2 meters high, has a groined ceiling and stone bench at the opening. On a lower level lies a cave called "the chapel," from which one descends seven steps to a path which bifurcates, one branch leading to the open, the other to a fifth cave, which has two stone columns in the middle supporting Gothic arches. Two additional caves with niches and benches are extended a few steps along the level of the meadow lands.

INHABITED CAVE DWELLINGS NEAR TOURS, FRANCE.

CAVE DWELLINGS AT ROCHECORBON, FRANCE.



CAVE DWELLINGS AT LAKE CONSTANCE, SOUTH GERMANY.

1. ENTRANCE TO OUTER ROOMS.

2. INTERIOR OF ROOM, WITH BENCHES, PILASTER, AND WINDOW.

CAVE DWELLINGS AT LAKE CONSTANCE, SOUTH GERMANY.

Regarding the origin and purpose of these Heidenlöcher there is not the least historical information. No one knows who built them or lived in them, how old they are, nor the purpose for which they were built. No chronicle nor historical record contains a single mention of them. Nothing has ever been found in the caves themselves which would aid in explaining them. In the family Beurer at Brunnensbach there figured for centuries as an heirloom a rare stone image which was found in the Heidenlöcher—a large piece of quartz, in form similar to a sitting man. This was perhaps of Celtic origin, for similar figures are frequently found in Gaelic graves; or, as others think, it may have represented "Godfather with the globe," pointing to the former use of the Heidenlöcher by Christians. * * * The results of the various theories may be summed up as follows: Our Heidenlöcher were originally but few, simply caves dug in the rock; they were in time enlarged, multiplied, improved, and embellished, and lastly treated with a sense of art. The small and simple ones are the oldest; they were the dwellings of the inhabitants of our region, first of the Celts, then the Suevians, the Romans, and lastly the Allemanni. The name Heidenlöcher must be ascribed to the Romans.

The modern history of these heathen caves is interesting.

As early as 1760 the city council of Ueberlingen ordered the destruction of the major portion of these caves because of their general use by low tramps and vagabonds.

When in 1846 to 1848 the new road was built between Ueberlingen and Ludwigshafen, a large portion of the Heidenlöcher cut in the cliff bordering on the lake was sacrificed. There are now only seven caves left of the former large number; they are visited annually by many tourists and are well cared for by the city as interesting relics of ancient times.

Joseph V. Scheffel has chosen these caves as scenes for some of the incidents of Ekkehard, an interesting story laid in the tenth century.

We must not overlook in our studies underground dwellings in England or such structures as the chambered mound at New Grange in Ireland, which may be described as roofed subterranean chambers, counterparts of which are found in other parts of the world. Rooms of this kind somewhat different in structure appear in the megalithic underground habitations, "weems" or "Picts' houses" of Scotland, and the Hebrides, the pit dwellings of Jesso, the subterranean rooms of the California Indians, and the "pit rooms" in southern Arizona. Spain has many artificial caves that were once inhabited, and those in full sight of the Alhambra in Grenada are still used by Spanish gypsies. Some of the Andalusian caves figured and described by Sr. Gongora, in his valuable memoir, Antiguedades Prehistoricas de Andalusia, closely resemble those of the southwestern part of the United States. Many accounts might be quoted in which the Etruscan caves, largely mortuary, are described. The remains found in caves along the Riviera, as those near Montone, have been described by several archæologists.

To enumerate all varieties of artificial caves, pit dwellings, and related forms of cliff dwellings would take me many hours—even a list of geographical locations where they occur would be of con-

siderable size. I should not omit to mention the monastic establishments and chapels of the Crimea built in caves, and those of the rugged Thessalian Mountains, views of which appear in plates 6 and 10.

Among the most interesting forms of Crimean troglodytic dwellings are those described by Prof. G. F. Wright in Records of the Past (vol 6, part 1) near Bakhtci-Sarai, the crypts of Katchikalen, and the "Valley of Jehoshaphat" (pl. 7). At the last mentioned locality there is a "promontory with precipitous faces on either side several hundred feet in height. The surface is covered by massive ancient ruins, while many passages lead down to extensive excavations with the windows open out upon the face of the precipice below."

Fergusson reports more than a thousand caves of architectural importance in the western part of India, and the cave temples of Ellora may be regarded as the culmination of Braminic cave architecture. There is a remarkable locality for the study of cave dwellings, called "The Thousand Caves," in the mountains of Koko-Nor, in Cambodia. The loess formation in certain parts of China is fairly riddled with artificial habitations. Mr. F. B. Wright has called my attention to caves of this kind at Shi-wan-tse, a place visited by him outside the Great Wall.

There might also be called to your mind the rooms inhabited by Greek priests, which have been excavated in large bowlders, and inhabited natural caves in the Caucasus Mountains; in some cases the cave mouth is filled in with an artificial wall made of stones, reeds, or bamboo. I can not do more than mention the cliff buildings of this kind reported from our possessions, the Philippines.

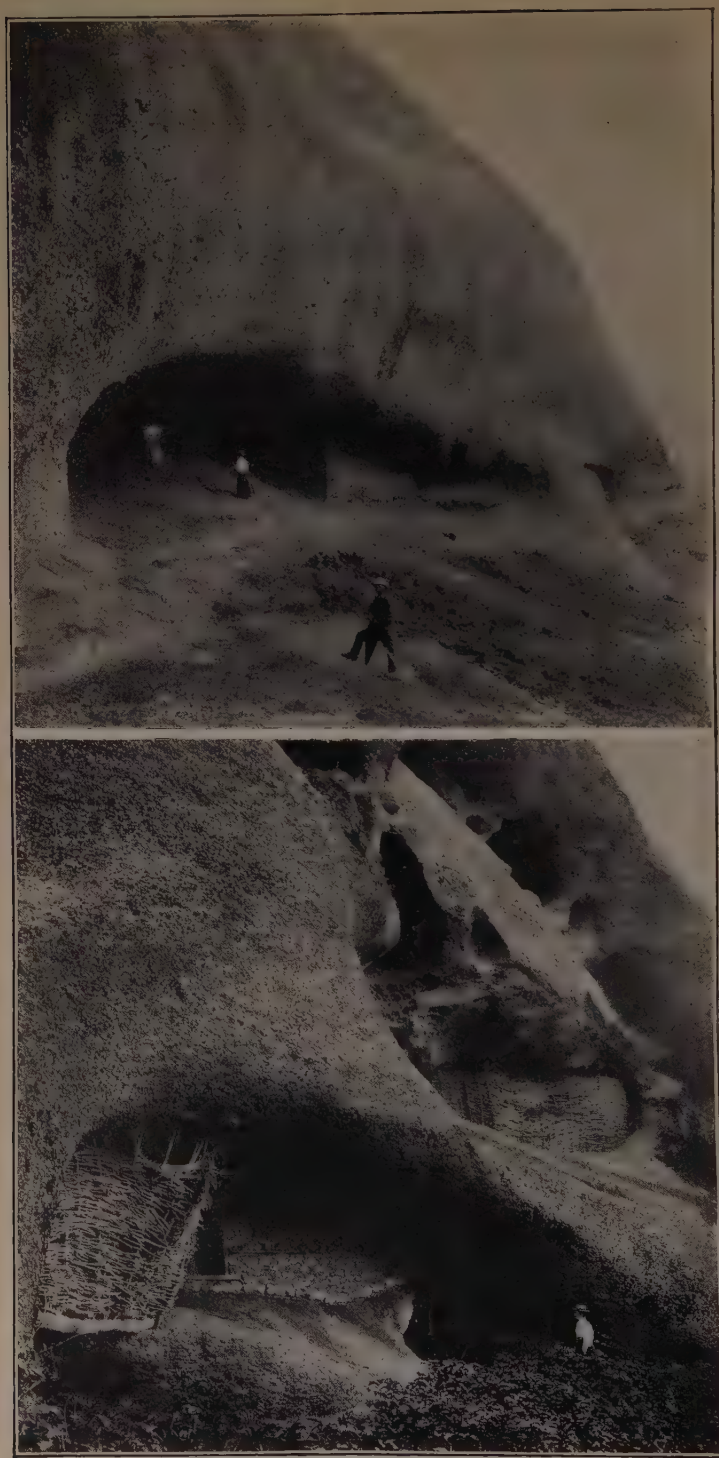
Certain climatic resemblances between the oases of the Sahara, in northern Africa, and the deserts of the Southwest have brought about remarkable similarities in habitations. We have in the Sahara region, extending from Egypt, through Tunis, Tripoli, and Morocco, to the west coast of Africa, a region of subterranean dwellings reproducing in appearances those common to the arid belt of the New World. It is instructive to note the similarity of these ancient Berber homes and certain Pueblo dwellings. It is perhaps more than a coincidence that we have coexisting among the former, as with the latter, two architectural forms, one above ground, the other below, the one a cliff and pit dwelling, the other an independent village.

The character of Tunisian Berber towns can best be illustrated by a typical pit habitation and town, and for this comparison I have chosen Matmata and Medinine. The village of Matmata (pl. 5, fig. 1), near Gabes, is certainly one of the most extraordinary underground settlements yet described.[1] As the visitor approaches it, we

[1] Die Troglodyten des Matmata, von Paul Traeger. Zeit. fur Ethnologie, 1906, p. 100.

1. MATMATA, SOUTHERN TUNIS, AFRICA.

2. MEDININE, SOUTHERN TUNIS, AFRICA.



CAVES WITH WICKER GRANARIES.

are told, he sees no sign of a village but only a number of cisternlike depressions in the earth, each measuring about 30 feet in diameter. But standing on the edge of one of these depressions and looking over the side into it what a strange sight meets his eyes. Deep in these sunken areas he sees the inhabitants, dogs, camels, and human beings. This depression is a breathing place or sunken plaza into which rooms open through lateral passageways, which are excavations in the walls of the depression. Some of these chambers are adorned with rugs and furniture. The sunken plaza is apparently the living place, entrance to it being by means of a subterranean tunnel, slanting upward, large enough for passage of man or beast. The troglodytic people which inhabit these subterranean chambers now number 1,200, and there is historical evidence that they have lived in these sunken pits for centuries. The court or sunken area into which the different rooms open is a common gathering place for the inhabitants, in which most of the household work is performed, the excavated chambers being often arranged one above another, serving as the sleeping rooms.

There are several of these troglodytic towns in the arid deserts of Tunis, some of them wholly below the earth's surface, while others are partly above ground. The reasons man has resorted to this subterranean life in this region are to escape from the torrid sun that fiercely beats down on the parched desert and to obtain shelter from the rain and sand storms. A remarkable similarity between pueblos on the one side and another type of Tunisian town like Medinine on the other is worthy of mention. Medinine, regarded by Hamy[1] as the Mapalia of Sallust, and probably the same as the troglodytic town mentioned by Strabo, according to Traeger, is composed of long, narrow rows of rooms destitute of windows, their doorways looking out on a common court. The rooms of this village, as shown by the doors, are built one above another, facing in the same general direction.

A comparison of the accompanying view of Medinine (pl. 5, fig. 2) and the Hopi pueblo, Oraibi, can not fail to reveal to the observer general likenesses with special differences. The buildings are four or five stories high, with lateral doorways at different levels. Of minor resemblance, visible in the figure, may be mentioned the steps, stairs, or other foot rests by which one ascends from the ground to the upper rooms. The row of these last, seen near the standing human figure about halfway up the side of the building, closely recalls similar projecting stones found in some of the cliff dwellings in Arizona, Colorado, and New Mexico.

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[1] La Tunisie au debut du XX Siècle, Paris, 1904.

Traeger and Bruun have pointed out that a Saharan town like Medinine is architecturally an imitation in relief of the subterranean village, Matmata, one being above the other under ground. In the southwest there is a similar relation of the cave dwelling and the pueblo built in the open.

The relative age of Matmata and Medinine, as representing the African troglodyte and a village in the open, may aid us in determining the relative age of the cliff houses or rooms in artificial caves and the pueblos. Traeger regards the dwellings underground as constituting the older or the original form, and it would seem that the same is also true in the New World where there is evidence that the cavate rooms are older than the pueblos. The existence of several-storied dwellings in the Sahara and in our Southwest are explained as follows. The limited capacity of the caves in America had so crowded together the inhabitants that they were compelled to construct rooms one above another, a condition of congestion which survives in the pueblo. The multiple-storied Berber villages in the open have a pueblo form for the same reason.

The Tunisian pueblos are inhabited by the Berbers, an aboriginal people of North Africa, whose ancestors, there is every reason to believe, lived in similar habitations in the earliest historic times. In fact, it is not impossible that the very people now inhabiting them are descendants of those who lived there in the time of Strabo or Sallust. It would appear that a residence for centuries in this peculiar form of dwelling may have led to certain habits of life which they share with our pueblos. It is foreign to the purpose of my address to enter into any intimate comparison of the culture of the sedentary prehistoric aborigines of the desert region of Africa with those of our Southwest, but it may not be out of place to state en passant that there are deep-seated similarities in their customs, arts, and institutions, which are heritages of a cave life. Instructive parallels, for instance, might be detected in house ownership, matriarchal rights, and clan descent between the two. It would be strange if their ideas of building were not alike.

To-day, as of old, the Berber tribes are distinct from the nomads and are reputed to live in stone-built hill villages with two-storied houses,[1] in marked contrast to the nomadic Arabs, who dwell in towns of tents. According to Ratzel, in villages of the western Atlas "the greater part of the upper story consists of a sort of rough veranda ill suited to the severe climate of that mountain country. * * * The natives pass the winter in cellarlike vaults beneath the houses; and for the sake partly of warmth, partly of defense, the houses are built so close together that they often produce the im-

[1] The upper story of a Kabyle village is ordinarily added after the marriage of a son.

pression of a village." This applies also to certain prehistoric Arizona house builders. It is not too great a stretch of the imagination to fancy that the former inhabitants of the Old Caves in the black lava hills that surround the San Francisco Mountains near Flagstaff, and those[1] in the neighborhood of the Black Falls, Arizona, may also, like the Berbers of the Atlas Mountains in Morocco, have retired in winter for warmth to their "cellarlike vaults beneath their houses." They likewise built close together, partly for warmth, partly for defense.

But cliff dwellings in the Old and New Worlds are not always limited to arid climates although they are elsewhere used for warmth, or retreats from cold wintry blasts. The Eskimo villages at King Island, in the Aleutians, is a noteworthy example of cliff dwellings overlooking the sea. This settlement, consisting of 40 dwellings, is literally lashed by cords to the side of a precipitous cliff, each habitation consisting of two chambers, an inner, partially excavated, and an outer constructed of poles or driftwood, the two communicating by a tunnel several feet in length. In the summer the hardy fishermen who inhabit this village live in the outer rooms which are little more than verandas, but in winter they withdraw to the excavated rooms for protection from the cold sea breezes.

The student of archæology of our Pueblo region has reason to congratulate himself on being able to interpret both major and minor antiquities by ethnological data. It is a great help when Pueblo priests, descendants of the ancients, can serve as mentors in archæological research. The same may also be said of the archæologist who attempts a study of the past culture of the cavemen of Morocco and Algiers, always considered in the greater perspective of time. Unfortunately the archæology of the Berber region, prior to acculturation and influx of foreign tribes, is almost unknown. A knowledge of the cave life of northern Africa, reaching as it does so far back in time, ought to aid us in comparison with more modern American cliff dwellings.

It rarely happens that so close a likeness between cave dwellings of the two hemispheres can be pointed out as in those found in Cappadocia and New Mexico. Perhaps the most striking types for comparison are the so-called "cone dwellings." None of the various cavate habitations of the Old World are more suggestive to the student of American cliff houses than those of the volcanic area west

[1] The Navaho call the Hopi, whose ancestors according to lengends probably lived in these ruins, the Ayakhini, people of (the kiva) underground houses. (See the Franciscan Fathers of St. Michael, An Ethnologic Dictionary of the Navaho Language, p. 135. This name is especially applied to Walpi.) When this name was given them, before the present Walpi was built, the ancestors of the predominating clans of the Hopi may have been living in underground houses at Black Falls or elsewhere.

and southwest of Mount Argæus and Cæsarea[1] Mazaca, overlooking the Huyler and the valley of the Geureme in Cappadocia (pl. 8, fig. 1). Many, perhaps the majority, of these were the works of Christian monks dating from the time of St. Basil.

Many travelers have commented on resemblances in the geology of Syria, Palestine, and the arid regions of our Southwest. In some parts of Asia Minor we find the geological formations of Arizona so closely reproduced that one is amazed at the similarities. In one as in the other there are regions of volcanic tufa eroded into fantastic shapes. We should expect to find in countries the geological features of which resemble each other so closely a similarity in human habitations.

This resemblance is evident in the cone dwellings near Martchan and those of the Otowi, New Mexico (pl. 8, fig. 2). These cones are geologically considered the last stages in the erosion of tufaceous cliffs and, as would be expected, we find associated with them all stages from the massive wall to a conical structure sometimes capped with the harder lava rock which has preserved it. The whole region in the neighborhood is volcanic in origin, and consists of a thick layer of tufa overlaid with lava which is comparatively thin. This tufa can be easily worked with primitive implements as stones or sticks; with a little patience chambers of any size could be excavated in it. Although some of the Asiatic excavations are 25 feet long by 13 feet wide, they might be made in a single month by one industrious workman.

In the past centuries the tufa has been eroded into deep canyons lined by cones often tipped by a lava cap 300 feet above the level of the canyon. In places the sides of these cones have been eroded, so as to expose the chambers in their interiors that are now used for drying grapes or other fruits. Ingress is generally by means of parallel holes arranged in rows which, when the sides have been worn away, are no longer visible. The rooms are commonly small, a fact that led the older writers on the troglodytes to speak of them as a dwarfish race, from which arose the supposition that the ancients knew of the race of pygmies in Africa. This supposition, that the cave dwellers are pygmies,[2] is world-wide in distribution, always due to the same

[1] Cæsarea was the home of Basil, the founder of the rule of St. Basil first accepted in Cappadocia, as far back as the fourth century, but others date back to a much earlier period.

[2] The most ancient sedentary people of New Mexico, Arizona, and Colorado which preceded the Pueblos lived in caves or pit rooms and practiced cremation. Their culture center was in the neighborhood of the Rio Grande. Another stock which also cremated their dead lived along the Gila and its tributaries. In early prehistoric times the Little Colorado Valley from Zuni to the Great Colorado, including Hopi, was practically uninhabited by sedentary people. Later it was peopled by colonists from these two cultural centers, possibly a race largely composed of extra-Pueblo peoples that did not cremate the dead.

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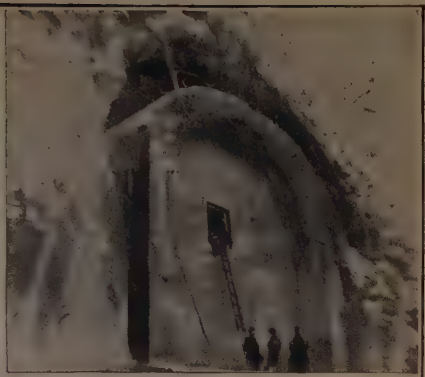

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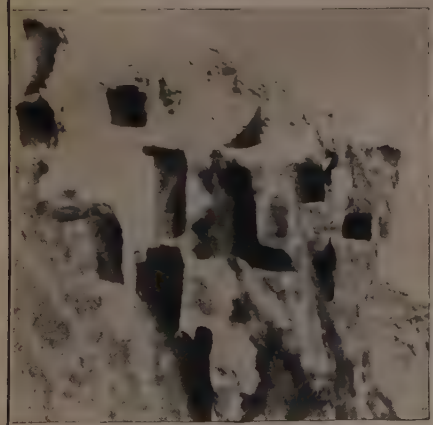

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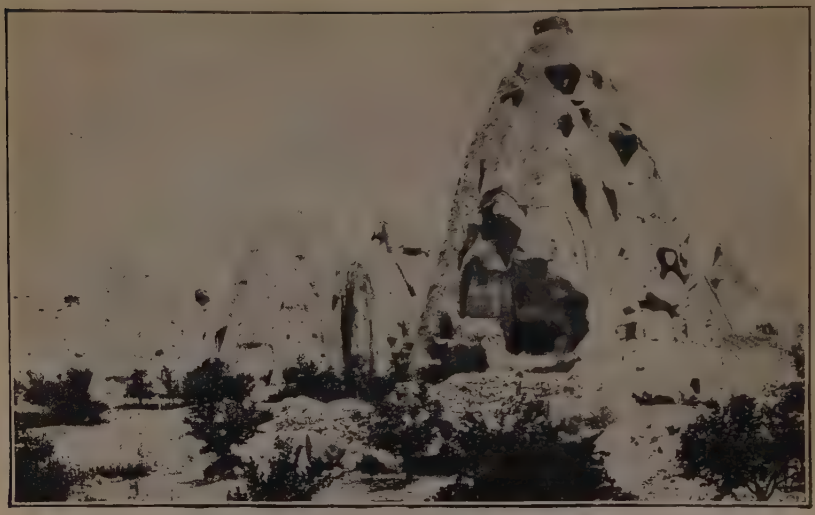
Photographs from "Records of the Past."

a–e, CRIMEAN CLIFF DWELLINGS; *f*, ROCK TOMB, AMASIA, ASIA MINOR.



1. Cone dwelling, Mazaca, Cappadocia. Photograph from "Records of the Past."

2. Cone dwelling, Otowi Canyon, New Mexico. From Bull. 32, B. A. E. Photograph by Craycroft.

CAVE DWELLINGS.

cause—the small size of the excavated rooms. Thus, although many people believe that the former inhabitants of the cliff dwellings of Arizona were pygmies, as every tyro knows, skeletons that occur in them do not support this theory.

On entering one of these cone dwellings of Cappadocia we find ourselves in a spacious chamber with shelves or niches excavated in the solid stone of the walls. The stairways resemble round tunnels through which one ascends to an upper story through holes like those lateral openings by which one enters the room. The floors separating the upper from the lower stories were usually thick enough to hold the weight that might rest on them, but occasionally these floors have given way and fallen to the floor below, thus enlarging both rooms and forming a lofty chamber. In one instance nine stories were counted, but generally there are one, two, or four stories, their position appearing on the outside as small windows or peepholes.

Many of the cave dwellers of Cappadocia have in front of the excavated rooms a portico later in construction than the room, as indicated by Greek or Roman arches and columns. In the interior occur also evidences of later occupation showing Christian origin or Byzantine culture. The customs of the natives living near the caves of this region differ slightly from those of an ordinary Berber village.[1]

I ask your permission to depart a little from the trend of my address and to consider the antiquity of these Cappadocian cave dwellings, many of which are no doubt comparatively modern monastic dwellings, though others reach back to a remote antiquity. Sayce regards Cappadocia as the original home of the Hittites, considering that in the hieroglyphy of this ancient people "cones are used as ideographs for king and country." If this be true the cone dwellings of Cappadocia were known and perhaps inhabited at the epoch of Hittite supremacy, or about 1900 B. C. Although these caves were probably inhabited before this remote time, no one has assigned them an older date.

Diodorus, Strabo, and other early historians or geographers of antiquity have embodied in their writings an account of the troglodytes living on the coast of the Red Sea written by Agatharcides about 250 B. C. This account is instructive as perhaps the oldest known historic record of the culture of cave dwellers. These troglodytes are described as a pastoral people, governed by chiefs who fought valiantly for their farms. "They made use of stone implements, spears, and arrows. Women always finally parted the com-

[1] For this material I am partly indebted to an instructive article by Prof. J. R. S. Sterrett in the Century Magazine for May, 1900, from which the statements here made are quoted. There is considerable general literature on the cave dwellings of Cappadocia, one of the most accessible accounts being that in Records of the Past.

batants, for their laws forbade a troglodyte to strike a woman. Their food consisted of meat of their herd, milk, and blood and of bones which were crushed and mixed with meat so as to form a kind of hash which was wrapped in raw untanned skins and roasted. Butchers were regarded as unclean persons. They slaughtered only old and sickly animals for food. They did not regard human beings as their ancestors but looked upon the cattle and sheep which furnished them food as their parents. They went nude or dressed in skins. Those who were too old to work committed suicide by hanging themselves by the neck to the tails of wild bulls, who dragged them to death. Cripples and those afflicted with incurable diseases were put to death. Herodotus says of the Ethiopian troglodytes that they were swift runners, fed on serpents and lizards, and had no real language but screeched like bats or twittered like birds."[1]

The highest form of cliff habitation in the New World is the cliff-pueblo which is practically a village built in a large natural cave. When the cliff dwellers of Colorado had arrived at such perfection in masonry that they could construct a village like the Cliff Palace of the Mesa Verde National Park they had progressed far beyond the primitive cave house. This was the highest and most characteristic American form of stone cliff dwelling north of Mexico and its counterpart is not known in the Old World.

There are true cliff houses of this type in Asia as well as in America. The examples which have been chosen for illustration of this point are cliff dwellings situated in Shansi, the northern Province of China (pl. 9, fig. 1). The cliff temple of the Mienshan Mountains, one of many in that region, lies in a great mountain cave which reminded Boerschmann[2] of the "Cave of Winds" behind Niagara Falls. Although there is no architectural resemblance between this temple and a cliff dwelling in Arizona (pl. 9, fig. 2), both are constructed under an overhanging cliff and it is interesting to note that the country in which both occur is semiarid. A necessity for shelter is not so evident in the Chinese cliff houses as in Colorado, but the same thought is apparent in the choice of the sites of these cliff houses. They show that in localities thousands of miles apart, where geological conditions favor the custom of constructing villages in natural caverns, there these structures have been found. It must be

[1] It is instructive to note the evidences of totemism and matriarchial descent that crop out in the above account. If we regard the Berbers or Tibbus as the lineal descendants of the cliff dwellers of North Africa, and the pueblos as living representatives of American cliff dwellers, several other common characteristics can be traced to a common influence.

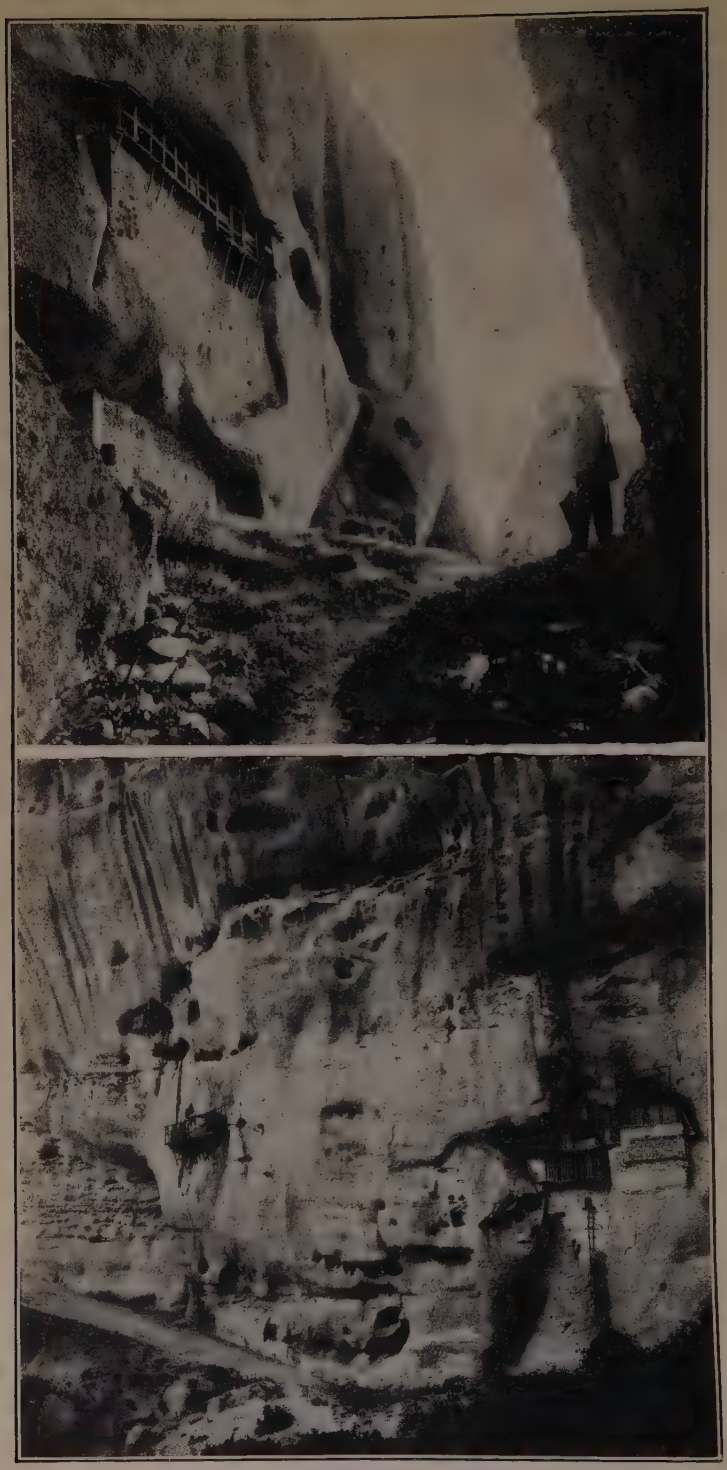
Dawkins says that "Dr. Livingstone alludes in his recent letters to the vast caves of Central Africa, which offer refuge to whole tribes with their cattle and household stuff."

[2] Ernst Boerschmann, Architektur und Kulturstudien in China, Zeit. f. Ethnol. 42. J. 3. 4. 1910. I am indebted to Herr Boerschmann for the use of his photograph of this temple.

1. Chinese cliff temple in the Mienshan Mountains, Shansi Province.

2. Cliff dwelling near Roosevelt Dam, Arizona.

CLIFF DWELLINGS.



MONASTIC CLIFF DWELLINGS, METEORA.

inferred, however, that, aside from the site occupied, the architectural features of the two are unlike although characteristic. The cliff temples in the Shansi are thoroughly Chinese, the Colorado cliff dwellings are aboriginal American, a diversity pointing to an influence to which the cave is secondary, to some power which is stronger than the external influence in its effect on the forms of cliff dwellings. While this power exerts itself strongly on the highest, it is not as potent on the lowest. The excavated caves of lower cultures in regions widely separated show closer resemblances than those made by more civilized men. The simpler the cultural life the closer its resemblance in different regions of the globe where environment is identical.

Another secondary use for caves which connects them with habitations and is found on both continents dating back to early times is their adoption for mortuary purposes. The cave originally built for a habitation in course of time is deserted by the living and becomes a burial place just as the subterranean cavern becomes a catacomb. This secondary use is connected with its adoption as a resort for priests, who would withdraw from the world for ceremonial or other reasons. The custom of burial in caves once established led to the construction of caves de novo for tombs and cave shrines, possibly temples, which latter are made difficult of access and isolated to add to their mysterious character. Ancestor worship and fear of the dead intensifies a feeling of awe, and other men are unwilling to enter caves which were once inhabited and now contain the dead.

Of many subjects connected with a comparative study of cave dwellings in the Old and New Worlds a comparison of burial places and tombs of the two continents parallel with that of habitations is one of the most instructive, but a consideration of this subject would manifestly enlarge my address to undue proportions.

Although examples of prehistoric tunneling occur in several localities in the New World none of these can compare in extent with the subterranean passages of Syracuse in Sicily.

As in the Old World, so in the New, the cave is a resort for the priest who remains there to intercede with supernatural beings. As a place of burial it is sacred and in it at times are kept the sacred images and paraphernalia of worship. A fear of the cave due to superstition is not wholly confined to the Old World but is also found in the New. Neither Navaho nor Ute, successors of the cliff-house people, would enter the cliff dwellings in early times before white men took the lead. Such an act would, they believed, bring direful ills, as blindness or even death, to anyone who ventured within these old habitations.

As the cave life is probably older in the Old World than in the New so the cave dwelling of that continent is the most highly developed architectually. Many of the rock temples of Egypt—as the far-famed rock temple of Abu-simbel—China, and India[1] are among the highest known examples of man's skill and expertness in rock cutting. Of all these none surpasses in interest and beauty the ancient far-famed cliff city of the Syrian deserts, called Petra.

Situated not far from an old caravan route across the desert from Damascus to Mecca and protected from nomadic marauders by its marvelous position, Petra has been occupied successively from most ancient times by Edomites, Phœnicians, Egyptians, and Romans, all of whom have left examples of their art in its rock-hewn temples and amphitheaters, shrines, and house walls. After passing through a narrow defile called the Sik, whose perpendicular walls tower above on each side, a visitor suddenly beholds the magnificent "Treasury of Ptolemy" cut on the side of the cliff. This beautiful temple, empty because without cave behind it, is but the beginning of a series of façades covering the high cliffs in the enlargement of the canyon, at the base of which lies in ruins the fallen walls of buildings long ago deserted. As one studies this greatest of all cliff cities,[2] built by human hands in the variegated rocks of a Syrian desert, he realizes the height cliff dwelling architecture long ago reached in the Old World, as a protection from foes by isolation. This ruin, with all its wealth of beauty, is connected with a desert and an arid climate, the same conditions which characterize its humble representatives in the New World.

I have sought for some explanation of the fact that the cliff dwellings and pueblos built in caverns are confined to our southwest and northern Mexico, and to the arid belt of Asia, Europe, and Africa. Why, for instance, is the distribution so circumscribed, especially when we find evidences that man elsewhere, as in the West Indies, once lived in a previous stage in natural caverns. I am inclined to recognize here the most striking instance of the influence of environment and geological conditions. Nowhere else were there caves capacious enough, open to the air, and in many other ways suitable for the erection of dwellings. Other caverns are deeper, the limestone caves of the Alleghanies are more extensive, some of those of the West Indies as inaccessible, but the majority have narrow entrances and are otherwise unfitted for the development of cave dwellings.

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[1] Emil Schlagintweit, Indien in Wort und Bild, Leipzig, 1890. Fergurson and Burgess, The Cave Temples of India, London, 1888.

[2] Alois Musil, Arabia Petræa, Wein, 1907. Gustav Dalman Hermann, Petra und seine Felsheiligtümer, Leipzig, 1908. Wm. Libbey, jr., and Franklin E. Hoskins, The Jordan Valley and Petra, New York, 1905. Also a popular account by the latter in the Geographical Magazine. See also Scientific American, 1900, et alii.

WASH HOUSE IN CAVE, SOUTH FRANCE.

A study of the cliff dwellings of the Old and New Worlds while showing, on the one hand, that surroundings have exerted marked influences in history, reveals on the other the weakness of the position that human history is solely a product of environment. If we were dealing with organic structures alone and the mind of man were wholly subservient to them, cave men throughout the world would have a greater uniformity in culture, but there is another factor in the case, there is the human mind and will with its powers of overcoming environment, and there is in man a strong desire for sociological and therefore institutional development. Man's mind, especially in the higher stages, is not altogether plastic to conditions; the desire to live in families, tribes, and other groupings is strong enough to offset climate and physicial conditions or to modify their influences as man wishes. Animals also have gregarious instincts, but these have not overcome environmental influence. Primitive man is also more or less subservient to it, but civilized man rises above external conditions, creating for himself sociologic and institutional laws independent of his surroundings.

It is evident that while cave life has exerted a marked influence on natural man in the creation of the monumental habit of building and thus led to higher civilization, this habit is only one influence acting on human culture history. The higher culture of man is more complex and due to more complicated influences than this would imply. History is the result of external environment, geological and climatic, but this cause is not the only influence acting on man's mind through the centuries. Whether we approach our subject from the historical, the cultural, or the geographical side we can not overlook the psychic or mind element in culture. It is instructive to see how in different regions of the earth natural man has been similarly influenced by like environment in constructing habitations, that limited influence from its nature is not lasting although in a measure hereditary but it will ultimately be powerless. Similarities of cave dwellings in widely separated geographical localities mean that the human mind in early conditions is practically the same everywhere, a principle that has the support of psychology. In later conditions the mind of the individual, while not necessarily superior to that of earlier times, enjoys the influence of accumulated survivals or the race inheritance of centuries of thought of other minds called culture.

NOTE.—Since the delivery of the above address several pamphlets and one or two books have been published on related subjects; the most important of the latter is by the Rev. S. Baring-Gould, on "Cliff Castles and Cave-dwellings of Europe." Among many instructive examples of European troglodytes, mentioned by the author of this work, the caves of Balmes du Montbrun near S. Jean de Cen-

tenier, in the Vivarais, are interesting in a comparative way. Here, according to Mr. Baring-Gould, is found a volcanic crater "300 feet in diameter and 480 feet deep; and man has burrowed into the sides of the porous lava or pumice a series of habitations, a church, etc." Similar excavations of habitations in the sides of a volcanic crater occur at the "Old Caves" near Flagstaff, Ariz. The view of the Cave Castle, Kronmetz, given by the same author, recalls several of the cliff-dwellings in the Canyon de Chelly and the Navaho National Monument. Many parallelisms to American pueblos in caves or cliff-dwellings may be found in European cliff refuges and cliff castles, although these structures are not as complicated in the New World as in the Old. One is strongly tempted to compare the prehistoric refuge platforms supported by beams found in some caves of France with the scaffold of Scaffold Ruin in the Navaho National Monument.

Mr. Baring-Gould brings out clearly in this work a most instructive fact in human geography, the relation of the European cave-dwellings to the chalk formation tufas and sandstones extending almost continuously from England to Asia Minor. In this we see relation of artificially excavated cliff-dwellings and geological conditions, a correlation that also exists in the distribution of cavate lodges, cave-dwellings, and easily worked geological formations in our Southwest.—J. W. F.

THE ORIGIN OF WEST AFRICAN CROSSBOWS.[1]

[With 1 plate.]

By Henry Balfour, M. A.

Considerable interest has been aroused in the discovery, now many years old, of crossbows in certain parts of western Africa, amid conditions of primitive culture; and the fact has given rise amongst ethnologists to speculation as to how a somewhat specialized weapon of this kind, which does not belong at all to African culture in general, has come to be adopted by uncivilized tribes in a restricted portion of the African continent. The range of the crossbow in Africa is very limited and more or less connected, and its isolation is a noteworthy feature.

To account for the presence of the crossbow in West Africa as an article of native manufacture and use, two alternatives are, of course, open to us. It must either be indigenous and have been evolved by the natives themselves, or its prototype must have been introduced from some foreign source. Paul du Chaillu, who recorded the use of a crossbow amongst the Ba-fan in 1861,[2] and who brought home specimens, two of which are now in the Pitt Rivers Museum at Oxford, does not offer any suggestions as to its origin, and is content with a description of its use. Sir Richard F. Burton,[3] on the other hand, in referring to the nayin (the native name of the crossbow among the Mpongwe of the lower Gaboon), describes it as "peculiar to this people and probably a native invention, not borrowed, as might be supposed, from Europe." The contrary opinion is, however, held by most modern ethnologists, and there seems to be but little doubt that the theory of the exotic origin of the West African crossbow is correct. There are probably few nowadays who seriously maintain that the weapon is either indigenous or of any considerable antiquity in the region. At the same time, the details in regard to the source whence it was derived do not appear to have been discussed, and I venture to bring forward some evidence of a very suggestive kind.

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[1] Reprinted by permission from the Journal of the African Society, London; No. 32, vol. 8, July, 1909.

[2] Explor. in Equatorial Africa, 1861, pp. 77, 78.

[3] Gorilla Land, 1876, vol. 1, p. 207.

Dr. Bastian[1] appears to have regarded the very simple "release" of the Fan crossbow as being due to the inability of the natives of the interior to imitate the complicated release-mechanism of European crossbows, and as representing merely the best they could do in the direction of imitation of a perfected type. Dr. F. von Luschan, too, speaks[2] of the method of discharging the Fan cross-

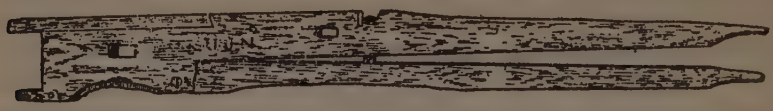

FIG. 1.—Side view of stock of Norwegian whaling crossbow (pl. 2, *a*).

bow as a degenerated derivative from a European form. I propose to offer evidence which renders unnecessary the view that the Fan weapon is degenerate, evidence which points to the native form being a direct and but very slightly modified imitation of an actual European type, itself of extremely rudimentary construction. In other words, my view is that the crossbows of the Ba-Fan and other allied native types are strictly primitive rather than degenerate.

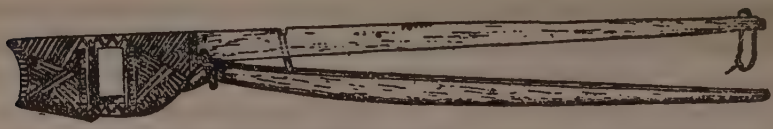

FIG. 2.—Side view of stock of crossbow from Oboru Kitty, in neighborhood of Benin, Nigeria, length 33½ inches. Collected by G. F. Martin. Pitt Rivers Museum.

Distribution and varieties of the crossbow in Africa.—Of the African crossbows the best known is undoubtedly that of the Fan and Mpongwe tribes of the Gaboon and Ogowe Rivers, of which numerous examples may be seen in museums. A typical specimen (pl. 1, fig. 1, *a*), collected by P. du Chaillu and belonging to the Pitt Rivers collection at Oxford, consists of a short and very rigid bow,

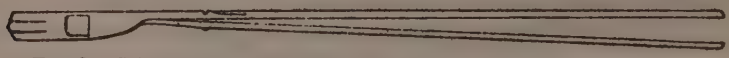

FIG. 3.—Side view of stock of Fan crossbow (pl. 1, *a*), length 50¾ inches.

25½ inches across the arc, having a nearly rectangular section, stout at the center, and tapering toward the ends. The bow is not straight in the unstrung state, but has a set curve when free from strain. It is set symmetrically through a rectangular hole near the fore end of a slender wooden stock, measuring 50¾ inches in length, and is fixed with wedges. This stock (fig. 3) is split laterally through-

[1] Zeit. fur Ethnol., vol. 6, 1874, p. (264), and vol. 10, 1878, p. (96).
[2] Zeit. fur Ethnol., 1897, p. (204).

out the greater part of its length, so as to form an upper and lower limb, whose hinder ends are free and can be forced apart, while they remain united in the solid for end of the stock. When the two limbs are brought together, a square-sectioned peg fixed to the lower limb passes upwards through the upper limb and completely fills up a notch situated on the upper surface behind the bowstring. The distance between the latter and the notch is 3½ inches, and this represents the full extent of the "draw." When drawn or set, the bowstring is held in the notch and the peg is forced downwards,

FIG. 4.—Side view of stock of Fan crossbow (pl. 1, *b*), length 52⅜ inches.

causing the two limbs to separate. By bringing these together again, with a squeezing action, the peg as it rises in the notch forces out the bowstring, and in this very simple manner the release is effected. There is a very faint groove in which the arrow lies.

The second example (pl. 1, fig. 1, *b*), also in the Pitt Rivers collection was obtained by the well-known West African traveler, R. B. N. Walker, from Du Chaillu, and is a very handsome specimen, delicately carved. It resembles in general the example above mentioned, but the stock (fig. 4) is somewhat longer, 52⅜ inches; the bow is

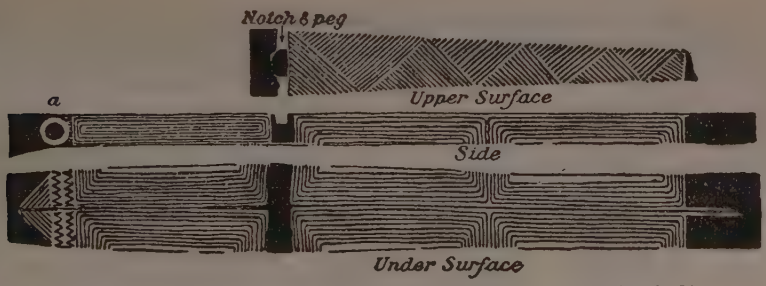

FIG. 5.—Details of carving upon Fan crossbow (pl. 1, fig. 1, *b*).

angular in outline, square in section at the center, and slightly con-
again later, is engraved upon either side. The chief point of de-
vex along the back; it measures 28 inches across the arc. The dis-
tance of the bowstring from the notch is 3¾ inches. The release peg
is semilunar in section, the convex edge directed forward. The stock
is very neatly carved in linear designs in the neighborhood of the
notch, the pattern extending as far forward as the union of the two
limbs (fig. 5), at which point (*a*) a small circle, to which I refer
parture from the other specimen lies in the stock being incompletely
divided. In the former example the two limbs of the stock are quite

separate at the hinder end (fig. 3), whereas in the present specimen they are reunited at this end, which is solid (fig. 4). This attachment of the two limbs at both ends accentuates the tendency of the lower limb to spring back when forced away from the upper, and the release becomes more automatic. When the bow is set the limbs are kept apart with a short stick, which is withdrawn to effect the release. In both examples the bowstring is of twisted bast or root fiber and a "whipping" or "serving" of fine yarn at the center protects it from friction against the stock. Du Chaillu, in describing the use of these crossbows, tells us that either iron-headed arrows or small darts poisoned with vegetable sap are shot from them. The little darts, being extremely light and easily blown away, are held in position in the arrow groove by means of a patch of gum. He tells us that they attain to a considerable range; that they are effective at 15 yards, and that the merest puncture kills immediately. He also speaks of the natives as good marksmen. The iron-headed arrows are about 2 feet long and are used for big-game shooting. In bending the bow, which is very strong, great force is required. The archer sits down, applies both feet to the center of the bow, and pulls the bowstring with all his force till it reaches and is held in the notch. Du Chaillu's illustration depicts the process. Sir Richard Burton also mentions that amongst the Mpongwe the dwarf bolt, ebe, is always poisoned with the boiled root of a wild shrub. He was not impressed with the marksmanship of the Mpongwe and never saw a decent shot made. He adds, "It is believed that a graze is fatal and that the death is exceedingly painful: I doubt both assertions." Comparing these two accounts by Du Chaillu and Burton, and assuming their accuracy, we may infer that the Ba-Fan were at the time the more skillful archers, and that they employed a more deadly poison that the Mpongwe. This is in keeping with the higher organization and culture of the former tribe, whose dominance amongst the other tribes of the region has been remarkable.

I have a note of a crossbow of the usual Fan shape from the Sanga tributary of the Kongo; but, unfortunately, I have no details regarding it. This type appears also in the Kamerun region, in the Ya-unde district, 4° N., 12° E., as may be gathered from a figure in a work upon the German colonies.[1] The Ya-unde people are believed to be closely related to the Ba-Fan. Sir H. H. Johnston[2] mentions the use of the crossbow among the Bali (N. Kamerun) and Indiki (Middle Kamerun), and also among the Baya tribes of the Sanga sources.

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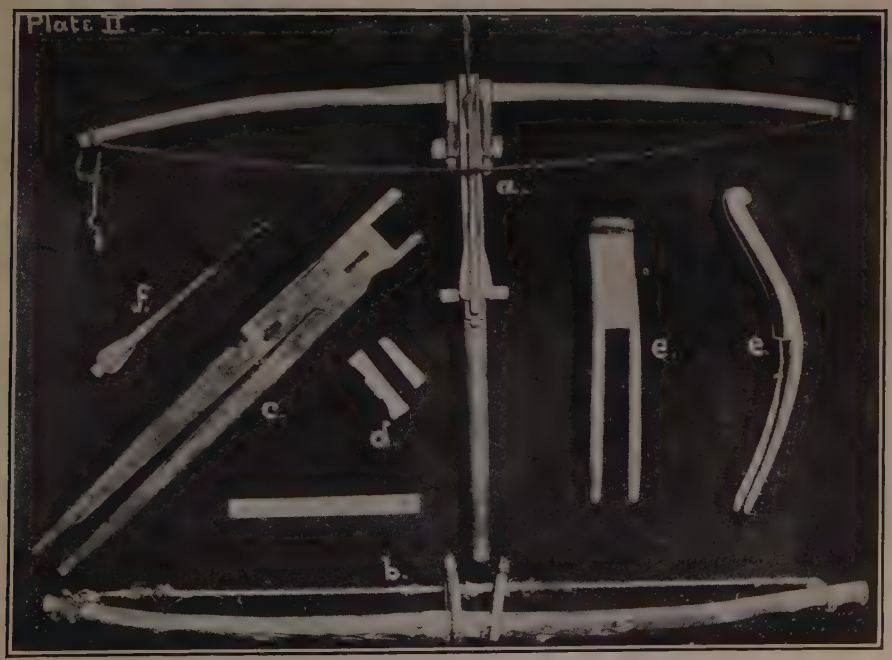
[1] Das überseeische Deutschland, 1890, p. 113. See also F. von Luschan, Zeit, f. Ethnol. Verhandl., vol. 24, 1892, p. 209.

[2] George Grenfell and the Kongo, 1908, vol. 2, p. 766.

1. *a.* Crossbow of the Ba-Fan, Gaboon, West Africa; length, 50¾ inches. Collected by P. du Chaillu, Pitt Rivers Museum, Oxford. *b.* Ditto, carved specimen; length, 52¾ inches. Collected by P. du Chaillu, Pitt Rivers Museum.



2. *a.* Whaling crossbow, Skogsvaag, Store Sartor, west coast of Norway. Specimen fully set up and ready for use, with bolt in position. Author's collection. *b–f.* Similar specimen with the parts separated. Collected by Dr. Bronchorst, Pitt Rivers Museum. (*b*, The bow with fixing collars; *c*, the stock; *d*, the bar and wedge by which the bow is held in position; *ee*, "goat's foot" levers for bending the bow; *f*, arrow or bolt.)

An interesting native crossbow (fig. 6) was presented by Capt. Latherington in 1832 to the Scarborough Museum, and is said to have been obtained on the "South coast of Benin" and to have belonged originally to a chief of the Mandingo tribe.[1] It is of dark-red brown and hard wood, polished. The bow is curved, 27 inches long and 1¾ inches wide at the center, tapering to 1 inch at the ends, which terminate in projections for the bowstring. The "back" is convex, the "belly" flat, and the edges are squared. The bow is passed through a rectangular hole in the thickened end of the stock and is fixed with wedges driven in from opposite sides. The stock is 24 inches in length, and consists of two parts (fig. 6, *c*). The upper part extends in one piece the full length of the stock, of which it forms the major part. The lower part consists of a separate bar or limb, fitting closely underneath the stock and butting against a sloping shoulder. A short distance behind the shoulder there is a

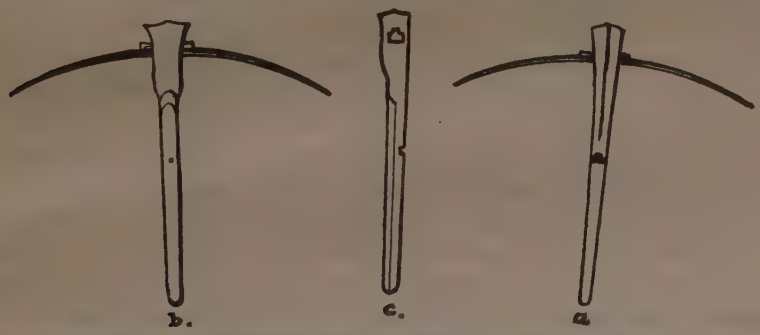


FIG. 6.—Crossbow of the Mandingo tribe, "S. coast of Benin," length 24 inches. Collected by Capt. Latherington. Scarboro' Museum. (*a*=upper surface; *b*=lower surface; *c*=side view.)

transverse hole through the upper limb, and a string loop passing through this embraces the lower limb and keeps it in its place, forming also a kind of rudimentary hinge uniting the two limbs in front and allowing their hinder ends to separate. The "release" is identical with that of the Fan crossbows, being effected with a notch-and-peg mechanism of precisely similar form. An arrow groove is also seen in this form (fig. 6, *a*). The principal difference between the Mandingo and the Fan types lies in the latter having a split stock while the former has the stock in two separate pieces hinged together.

In the Yoruba country the crossbow is used among some Yoruba-speaking tribes in conjunction with the long bow,[2] and a local proverb referring to them has been recorded by Bishop Crowther of the

[1] I am indebted to Dr. John Irving, of Scarborough, for details and sketches of this specimen.

[2] Gov. Moloney, Journ. Anthrop. Inst., vol. 19, 1890, p. 213.

Niger: "A crossbow is not enough to go to war with; whom do you dare to face with a stick?" Gov. Moloney produced examples of crossbows through the chiefs of Ibadan. They are called in Yoruba akatanpó (the long bow being called oron or orun). The release is like that of the Fan and Mandingo forms, i. e., effected by means of a divided stock with peg and notch. The bow is drawn, as is that of the Ba-Fan, with the aid of the feet. The string is of bast, twisted fiber, or animal skin.

In the Pitt Rivers Museum at Oxford there is the stock of a crossbow (the bow is missing) which closely resembles the Mandingo example (fig. 2). It was obtained by Mr. G. F. Martin from a Benin tribe at Oboru-Kitty, about 14 miles from the right bank of the Niger and 30–40 miles east of Benin, and was presented by him to the museum in 1902. The length of this stock is 33½ inches. The head is carved in rectilinear designs. The loop which forms the hinge uniting the two limbs is of cane, and allows the free ends of the two limbs to separate to the extent of 3 inches. The release peg is fixed to the lower limb somewhat diagonally, pointing forward. From the shape of bow slot we may gather that the bow was rectangular in section. There is a well-marked arrow groove upon the stock, and close to the notch there are traces of wax, evidently employed for causing the arrow to retain its place until the detente.

It is clear, I think, that the Mandingo, Yoruba, Beninese, and some of the Kamerun crossbows which I have mentioned are closely related to those of the Ba-Fan and Mpongwe. The principle of the detente is identical in all, allowing for the difference between the hinged and split stocks; the tendency of the bows toward a rectangular section, the arrow groove and the use of wax to keep the darts in place, are all features common to these varieties of the weapon. That these crossbows form one family group with local variations can hardly be doubted.

Dr. F. von Luschan has described and figured [1] a peculiar form of crossbow from the Ba-Kwiri in the hinterland of Kamerun. Two specimens were obtained by Lieut. Freiherrn, and are now in the Berlin Museum. This type differs from those already referred to in certain prominent characteristics. The crossbow itself is of small size, the length of the stock being about 34 inches, but the total length is enormously increased by the addition of a wooden barrel nearly 5 feet in length, through which the featherless darts (about 10 inches long) are discharged. In use, the bowstring is drawn back into a notch, as in other West African crossbows; but, unlike the latter, there is no mechanism for the release. The stock, which is shaped in imitation of that of a European musket, is solid and not divided, and

[1] Zeit. für Ethnol., 1897, p. [204].

there is hence no peg with which to push the bowstring out of the notch; this action is performed simply with one of the archer's fingers. In respect of the detente, this particular type appears, as von Luschan justly remarks, to exhibit degenerate rather than merely primitive characteristics. An almost identical form of crossbow with long barrel and stock of European shape, from Buea, Kamerun, may be seen in the missionary museum at Basel. Crossbows fitted with barrels are everywhere uncommon, though I have noted in the Berlin Museum an example from Goram Island, in the Malay Archipelago. A barrelled crossbow was much in use in western Europe during the seventeenth century.

Although the distribution in Africa of the crossbow as a serious weapon is so restricted—being confined mainly within the limits of the region extending from the Mandingo country to the Sanga and Gaboon districts—there are to be found outside this area certain appliances in which the general principle of crossbow mechanism is adopted, and to which brief reference may be made. J. A. Grant mentions toy crossbows as in use in 1861 among the children at Ukuni in the Unyamwezi country to the south of the Victoria Nyanza.[1] Mr. Emil Torday discovered among the southern Ba-Mbala of the Kwilu district in the Kongo State a toy crossbow used by children for shooting seeds and berries.[2] In this the form of the stock, which is of palm midrib, is clearly modeled upon a European gunstock, and the method of release, by means of a toggle and short string attached to the bowstring, is, to the best of my recollection, only to be paralleled amongst crossbows with the crossbows of the Nicobar Islands. Sir H. H. Johnston also mentions the use of toy crossbows among the Ba-Yaka and the Ba-Kongo. These various miniature crossbows, which may very likely be still more widely dispersed in Africa, have but little in common with the West African crossbows with divided stock, and they may well be regarded as referable to a different origin, and as having been introduced independently into West Africa via the northeast and through Moslem influence, as has been suggested by Sir H. H. Johnston.[3]

Again, there is that peculiarly widely distributed appliance, the crossbow trap, varieties of which are to be found in so many widely separated regions of the world. Rat traps of crossbow form are familiar appliances in the French Sahara and Bornuese territory and occur also in German East Africa and, no doubt, elsewhere in Africa; but it may be doubted whether these have any direct morphological connection with the true West African crossbow weapons, and it is unnecessary to consider them in detail in the present memoir.

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[1] A Walk Across Africa, 1864, p. 100.
[2] Figured and described in Man, 1907, No. 52, fig. 2.
[3] George Grenfell and The Congo, 1908, vol. 2, pp. 766–767.

Origin of African crossbows.—I have now described the varieties and distribution of the crossbow in Africa as far as the evidence at my disposal allows, and it remains for me to deal with the interesting problem of its origin in this part of the world.

The theory of an indigenous origin for the crossbow in West Africa, which has been held by some authorities, e. g., Sir R. F. Burton, has, it would appear, been put forward in the belief that the West African forms are of a far more rudimentary type than any European forms, and that the differences between the crossbows of the two regions are such as to preclude their having a common origin, the crude and peculiar method of effecting the release being the principal distinguishing feature in the African examples. Those observers, on the other hand, who maintain, as I think rightly, the exotic origin of this West African weapon, have endeavored to account for the extremely simple release mechanism by urging that this is a degenerate form, arrived at as a result of attempts on the part of the savage to approximate to the more complex European mechanism, and representing the best that he could do in this direction. Both these views are, I believe, based upon a misconception, and are due probably to their promoters being unacquainted with one very interesting type of European crossbow, which to my mind furnishes the key to the solution of the problem.

The theory of indigenous origin may, I think, be finally dismissed. I propose to bring forward evidence which gives one good ground for believing that the Fan and some other West African crossbows are neither degenerate to any extent, nor even more primitive in construction than some rude types of crossbow which remain even at the present day in practical use in northwest Europe.

Although it is unlikely that the crossbow is of any considerable antiquity in West Africa, we may feel sure that it is not at any rate a very recent introduction among the natives of this region. Du Chaillu, Burton, Walker, and other early explorers of the inland regions, found the weapon well established and in general use among the Ba-Fan and Mpongwe tribes of the Gaboon district, among whom it had assumed a well-defined and constant type, subject only to minor variations. The opening up of other parts of West Africa has here and there revealed the use of native-made crossbows, which also exhibit a considerable uniformity of type, though well-defined local varieties occur, as I have pointed out. The general uniformity leads one to assume that all, or nearly all, are traceable to a common prototype. These weapons are likely to become obsolete very soon, since, just as the general use of the crossbow in Europe died out as a result of the successful rivalry of firearms, so the process is being repeated in Africa to-day, where European muskets are rapidly ousting the descendants of the European crossbow.

It seems to me unlikely that the crossbow was introduced into West Africa overland from the northeasterly portion of the continent—though this has been suggested by some[1]—since this weapon, though probably known in early days through European contact, can not be regarded as characteristic of or as having been adopted in that part of the world, which is therefore unlikely to have afforded the source of inspiration through the medium of Arab traders and explorers. The more probable and more generally accepted theory is that West Africa owes the crossbow directly to western Europe, and I hope to show that this theory is far more plausible even than is generally supposed.

The reputed French trading adventurers of the fourteenth century, the Portuguese explorers from the middle fifteenth century onward, and the Dutch, English, and Danes, who followed closely upon their heels and vied with them for commercial supremacy, may be regarded as the possible introducers of the crossbow into western Africa, in the region of the Bight of Benin, the scene of their keenest investigations and most strenuous rivalries. The famous bronzes, cast by the cera perduta process by the natives of Benin, afford evidence of the use of the crossbow as a weapon by invading Europeans in the sixteenth or seventeenth century. A bronze plaque in the British Museum[2] carries a figure in relief of a European, probably of the sixteenth century, carrying a crossbow (Fig 7, *a*) and three different kinds of bolts or quarrels (pointed, blunt headed, and chisel ended), and the realistic manner in which these are portrayed is evidence of an accurate appreciation of their utility and detailed construction by natives already acquainted with the long bow. On the other hand, none of the numerous figures of armed natives represented upon these bronzes are equipped with this weapon, and this negative evidence may be regarded as indicating that the crossbow was still purely exotic at the time, and had not yet been adopted

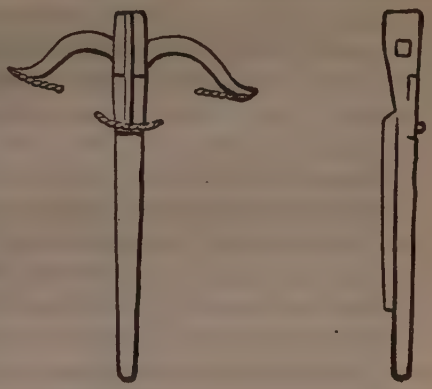

FIG. 7.—European crossbow, represented in relief upon a bronze plaque, from Benin, in the British Museum. (*a*=upper view; *b*=side view.)

[1] Sir H. H. Johnston in his book already referred to, as also in a letter which he kindly wrote to me, expresses the opinion that the crossbow reached West Africa by two routes: (1) from Egypt, where it was introduced in Crusading times, and thence transmitted by Moslem influence, (2) from Portugal by the West Coast sea route.

[2] Figured by Read and Dalton in The Antiquities of Benin, London, 1899, pl. 14, fig. 1.

and imitated by the native craftsmen of this region at any rate; while a suggestive clue is afforded as to the possible date at which an appreciation of the capabilities of the foreign weapon may have led to early attempts by the natives to produce weapons of similar type.

It is generally supposed that the art of the bronze founders of Benin was itself introduced from western Europe, and the Portuguese have usually been suggested as the likely teachers of the process. This very plausible theory is not, however, conclusively proved as yet, and arguments against it have been presented by Mr. H. Ling Roth.[1] Be this as it may, even if we assign to the Portuguese the credit of having introduced to the natives the difficult art over which the latter obtained so complete and remarkable a mastery, it is not necessary to assume that every European represented upon the plaques and other castings is of necessity a Portuguese. Once the art was developed by the natives, any Europeans with whom they came in contact would be equally liable to have their characteristics portrayed, and, as I have pointed out, there were among the early explorers of the region not only Portuguese, but also Europeans of French, English, Dutch, and Danish nationalities. It is of importance to bear this in mind in connection with the probable introduction of the crossbow.

The prevalent idea that the native African crossbows are degenerate imitations of European forms is based upon the notion, a perfectly true one, that the well-known types of this weapon used for military and sporting purposes from the fifteenth century onward were complex weapons of elaborate construction, involving a bow of steel, an elaborate wooden stock, and a skillfully designed and complex mechanism for the release. This is undoubtedly so, the crossbow having already been in use for centuries in Europe, and having been developed through successive stages of improvement into a highly perfected appliance. It had reached almost the zenith of its development. At the same time, we should not lose sight of the fact that not only had more primitive types necessarily existed—prototypes whence were derived the later, improved forms—but, further, that under certain conditions some of these archaic forms persisted into quite late times, and continued to be manufactured alongside of the more perfected varieties. The older forms survived, in fact, as long as their simpler construction and relative cheapness continued to supply a want.

Now, in a single small district on the western coast of Norway there may still be seen in serious use a form of crossbow which it would be hard to parallel for simplicity and rudeness of construction. It seems like an anachronism in an environment of highly specialized weapons of modern type. It is, however, no mere plaything, but an appliance of practical utility, upon which the livelihood of its

[1] Great Benin, 1903, Chap. 19.

owners largely depends. In former times, no doubt, it was far more widely dispersed, but, having been gradually given up or superseded by improved weapons, it is now reduced to a state of struggling survival in its last home, whence, too, it will finally disappear ere long. The district in question is the southern portion of Store Sartor, a large island adjacent to the port of Bergen.[1] The island is deeply cut into by three narrow fjords, Ostfjordspollen, Tellevaag, and Skogsvaag. These fjords are visited periodically by whales, especially by the Lesser Rorqual, *Balænoptera rostrata*, the "Vaagehval" of the Norwegians. The capture of these cetaceans is a matter of considerable concern to the inhabitants. For the details concerning this local whale fishery I must refer readers to Dr. Brunchorst's interesting paper. Suffice it to say that when one or more whales have entered the fjord their retreat is cut off by a net drawn across the narrowest part, and they are then killed from boats by means of the extremely crude and barbaric crossbow which I will now describe (pl. 1, fig. 2). Several years ago I procured one of these whaling crossbows through a friend in Bergen, and lately a second example has been sent to me by Dr. C. G. Seligmann, who obtained it from Dr. Brunchorst. The construction is as follows: The bow (pl. 2, *a* and *b*) is of large size and very stout, roughly hewn out of yew (*Taxus baccata*) procured from the Hardanger; it tapers somewhat toward the ends, which are "shouldered" for the bowstring. The latter is thick and of tanned hemp, in strands loosely twisted into a cord which is "served" at the center to protect it from friction against the stock. The stock (pl. 1, fig. 1 *c*, and fig. 1) is of ash, and consists of an upper and a lower limb. The upper limb, or stock proper, is deep at the front end and terminates in two projections forming a fork in which the bow lies. Close behind the fork is a rectangular perforation, and further back its lower edge is cut suddenly away to form a sloping shoulder. From this point the limb tapers gradually away to its hinder extremity. A short distance behind the shoulder a short, flat bar of wood is set transversely through the stock, its ends projecting on either side. A little behind this the stock is perforated in a vertical direction, and is notched to receive the bowstring when the bow is drawn or set. To this upper limb, or main portion of the stock, is attached the lower limb, which is shorter and butts up against the shoulder to which it is hinged by means of a tenon and wooden pin or rivet. This limb also tapers toward its hinder extremity. A stout wooden peg fitting loosely in the vertical hole in the upper limb is driven into the lower limb, to which it is firmly fixed. The hinge joint uniting the limbs enables their free ends to be separated

[1] An interesting illustrated paper upon the construction and use of this crossbow, "Hvalfangst med bue og pil," written by Dr. J. Brunchorst, appeared in Naturen, issued by the Bergen Museum, 1899, pp. 138–154. I have borrowed from this account many of the details here referred to.

or closed together. The bow is fixed firmly in position in the forked end of the stock by means of a pair of wooden collars, each formed by bringing together the ends of a flexible split rod and binding them together to form a pear-shaped ring. These collars encircle the bow and brace it to a transverse bar (pl. 1, fig. 2 *d*), which passes through the forward rectangular hole in the stock, and are tautened with a wedge. In use, the bow is "set" by drawing the bowstring backward until it is caught in the notch on the upper surface of the stock, the limbs being separated so as to withdraw the head of the release peg from the notch. The huge bow is too powerful to be bent by hand, so the operation of drawing is performed with a simple but effective wooden "goat's-foot" lever (pl. 1, fig. 2 *e*, *e*), the prongs of which rest against a fulcrum formed by the ends of the transverse bar immediately in front of the notch. The arrow or bolt (pl. 1, fig. 2 *f*)—which consists of a head and foreshaft of iron set in a shaft of pine "feathered" with thin wooden slips—is laid in the arrow groove, the slightly notched butt being just in front of the bowstring notch. To discharge the bow, the two limbs of the bow are simply squeezed together, with the result that the release peg is driven upward through the notch, out of which it forces the bowstring, which drives the bolt in front of it. Experience has taught the peasant whalers that new or cleaned bolts are far less deadly than old and uncleaned ones, the reason for this being that the latter are highly poisonous from the septic condition of the decaying matter adhering to the rusty surface of the iron heads, which are never burnished. They are even buried sometimes in gangrenous flesh so as to induce this septic condition. The true nature of the poison is, however, unknown to the peasants.

The simple release mechanism of this modern Norwegian crossbow, it will be at once noticed, while differing completely from that of all other European crossbows, whether ancient or modern,[1] is precisely similar to that of the crossbows of the Ba-Fan, Mpongwe, Mandingo, Yoruba, and Benin natives of West Africa, which I have already described. The identity in structure is so absolute that it is impossible to avoid the belief that all are traceable to a common origin. It is most unlikely that this contrivance, which, simple as it is, required some real ingenuity for its invention, should have been independently arrived at in two widely separated regions of the world, by a civilized people in the one region and by a savage people in the other. The probability of the crossbow having been introduced into West Africa by Europeans in the sixteenth or seventeenth century becomes almost a certainty when we know that the structural details of the African forms are actually those of certain European crossbows. It was only ignorance of this fact which has caused any hesitation in accept-

[1] Sir R. Payne Gallwey makes no mention of the Norwegian wooden crossbow in his important monograph on the crossbow.

ing the theory of a European origin. The principal difference existing between the crossbows of the Goboon and of Norway, the two extremes, lies in the fact of the Scandinavian examples having the lower limb of the stock hinged to the upper (fig. 1), while the Gaboon type has the stock made in a single stave, split to form the two limbs (figs. 3 and 4). This distinction is at the best a minor one, and is due probably to the lowly cultured savage not comprehending readily the structure of a hinge joint. In any case, this difference becomes quite insignificant in the light of the Nigerian and Mandingo crossbows (figs. 2 and 6), which effectively link the two extremes together, and in which we see a hinge joint of a simplified type, a loop replacing the more complex tenon-and-rivet joint of the Norwegian whaling crossbow. A significant piece of evidence, helping further to link the latter with the Gaboon weapon, is to be noted in the Fan crossbow represented in fig. 4 (and pl. 1 fig. 1 *b*). It will be noticed that just at that point (figs. 4, *a*, and 5, *a*) where the end of the wooden hinge rivet of a crossbow of the Norwegian type would be seen [cf. fig. 1], an engraved circle appears. This is quite distinct from the rest of the carved decoration, and may well be a "skeuomorphic" reminiscense of the hinge of the European prototype, which in this particular it was impossible to imitate so as to form a practicable joint. Or, and perhaps this is rather more probable, this circle may represent the perforation in the upper limb of the stock, through which the loop forming the hinge of a Nigerian crossbow is passed. In either case this design seems to point to the Gaboon weapon having been derived from a model of the hinged variety, and serves to link the various local forms together. Viewed in the light of the other correspondencies, this decorative feature acquires a phylogenetic value of considerable interest.

The European origin of West African crossbows, notably those of the Gaboon district, is further exemplified in the form of the bow itself, which is clearly modeled upon the rectangular-sectioned steel bows of the European type, and differs completely from any native long bows. Here there is a departure from the crude Scandinavian type, but it seems very possible that the simple method of release which still survives in the clumsy Norse weapon may also have been applied to better-class weapons fitted with steel bows. Indeed, an examination of the form of crossbow represented upon the Benin bronze plaque in the British Museum (fig. 7, *a* and *b*) affords most suggestive corroboration of this view. The bow there shown is evidently of steel, and is of the "Cupid's-bow" form. The stock is evidently in two parts, with a movable lower limb recalling the structure of the Norwegian stock (fig 7, *b*). The lower limb as represented is, however, decidedly shorter than the upper, and it may be urged that we have here merely a clumsy representation of the long

steel lever which held and released the revolving catch or "nut" of the typical medieval and later European crossbows. This may be so, but there is undoubtedly a greater resemblance to the divided stock (with peg-and-notch release) than to the stock with lever and "nut" mechanism, and there is no suggestion of a revolving "nut" in the simple transverse groove which appears to represent a plain notch for the bowstring. Moreover, when a lever was employed this necessarily did not extend farther forward than the catch which held the bowstring, whereas, in the crossbow represented upon the plaque, the union of lower and upper limbs is placed considerably in front of the notch, as is the case in all the crossbows having divided stocks—a significant fact. It has occurred to me that the lever of the better-known European crossbows may itself have been suggested by and derived from the movable lower limb of the ruder types. The muscular action required to effect the release is in both cases the same, viz, a squeezing together of the two parts of the stock in the one case, and of the lever and stock in the other; the revolving wheel-like "nut" in the latter form having supplanted the more sluggish thrusting-peg action of the former. But this is by the way. The combination in many of the African crossbows of a bow apparently modeled upon a steel original, with a simple divided stock, may thus perhaps be explained by the evidence as to the introduction by Europeans of a crossbow in which these characters are actually combined, as recorded upon the bronze plaque from Benin.

One can not readily determine which of the European peoples may have first introduced the crossbow with divided stock into Africa. This primitive form, now restricted to a very limited area in Norway, was probably at one time far more widely distributed over Europe, and the Portuguese may quite well have known and used this type, and have carried it with them to West Africa; but the probability lies, perhaps, rather with the Danes or the Dutch, who may be regarded as more likely to have employed a form which we know to have been associated with Scandinavia. In this case the introduction would not have taken place earlier than the later portion of the fifteenth century. The European figures upon the Benin bronzes appear for the most part to belong to the sixteenth century, and the Beninese bronze founders were sufficiently familiar with the European crossbow to represent it with wonderful accuracy in matters even of detail. May we not regard it as probable that the weapon was first adopted in the sixteenth century by the natives of Nigeria, who to this day are using a hinged form of crossbow with divided stock, and that from this region the weapon was dispersed, varying somewhat in detail as its range extended farther from the original center, and becoming simplified to some slight extent as it

reached the more remote tribes of yet lower culture, such as the Ba-Fan and Mpongwe, amongst whom the stock of the crossbow is merely split instead of being hinged. The simplification is in any case so slight that it can hardly be said that the crossbows of the Gaboon district are really a degenerate development, as compared with such a European form as I have suggested may have been their prototype. If on the one hand the release mechanism is slightly degraded, on the other hand in point of finished workmanship the Gaboon examples are far superior to the Norwegian. The change from a hinged stock to a split stock is associated with the gradual disappearance of the arrow groove, owing, no doubt, to the use of much lighter arrows which are held in position with wax or gum. This method of causing the dart to adhere to the stock is employed also in the case of the native hinged crossbows, in which the arrow groove is often well defined, though usually much less so than in most European crossbows; in this respect, too, therefore, the Gaboon type is linked to the European indirectly by the Nigerian type. It is most unlikely that the crossbow-using natives of the Gaboon received the idea of making this weapon direct from Europeans, since they appear to have only recently migrated toward the coast from the interior. In their former home they would have been out of reach of contact with the early European explorers; and apart from this, the special features of this local type are most readily accounted for as due to indirect connection with the European prototype and to the distance from the original center of dispersal in West Africa.

The method of release with a divided stock is paralleled, as far as I am aware, in but one other region of the world. The well-known and specialized repeating crossbow, nou koung, of China is discharged in a manner closely analogous to the mechanism of the West African and Norwegian forms which I have described. I must not here enter into the possible affinities of this Asiatic form, but merely refer to it as having certain marked characteristics in common with these western types of crossbows.

As regards the Ba-Kwiri crossbow of the Kamerun described by Dr. von Luschan, we may judge from its structure that, while it is probably allied to the other West African forms, it is a strictly degenerate variety of the weapon as regards its mode of discharge, since there is no mechanism for the release, which is effected by merely pushing the bowstring out of the notch by hand. The form has evidently been much modified through imitation of firearms, as the form of stock and the long barrel prove. We must regard this form as an aberrant local type which has developed largely upon lines of its own, diverging from the more usual type.

To sum up briefly. It appears to me that the exotic origin of the West African crossbows is practically certain. The evidence points to the prototype of those crossbows which have divided stocks having been a European crossbow of a type nearly related to that which now survives only in western Norway, where it has persisted for a special purpose. It seems probable that the introduction of this weapon into West Africa was effected by the early European expeditions, probably some time in the sixteenth century, and that the natives of Nigeria were the first to adopt it from them; also that from this center it was dispersed westward to the Mandingo country, and eastward through the Kamerun district to the Gaboon, and that the local varieties are for the most part, at least, derivatives from one original prototype.

SANITATION ON FARMS.[1]

By Allen W. Freeman, M. D.,
Assistant State Health Commissioner of Virginia, Richmond, Va.

The careful student of sanitary progress in the United States today is early impressed with the great contrast between the sanitary conditions in country districts and those in the cities. Recent years have witnessed great progress in the cities. Effective health departments have been organized, and the effect of measures, such as the supervision of water and milk supplies, the visiting nurse, and the tuberculosis dispensary, medical inspection of schools, and the accurate control of contagious diseases, has been so pronounced as to place their work on a firm basis, and to insure its continuance and extension. While much remains to be done in the cities, the foundation has been laid and the methods of work more or less standardized. It is not too much to say that we are within sight of the solution of many of the problems of municipal sanitation.

While these facts are true of the cities, in those States with which we are familiar no such condition exists in the country districts. They remain as they have been for years, without efficient organization, depending on the methods and beliefs of 30 years ago. In only a few States is there adequate supervision of the rural communities; only a few States require the reporting of even the most dangerous of contagious diseases, and in most cases what activity there is in the country districts is confined to the control of smallpox, diphtheria, and scarlet fever, with occasional attention to a flagrant nuisance. The vast contributions of modern science to the prevention of disease are for the most part lost to the people of the country for the lack of organization and education. There are, of course, isolated exceptions to this statement, such for instance as the wonderful work of the Pennsylvania department of health in connection with tuberculosis in rural districts, but for the most part conditions are as stated.

[1] Read in the section on preventive medical and public health of the American Medical Association, at the sixty-first annual session, held at St. Louis, June, 1910. Reprinted by permission with author's revision from Journal American Medical Association, Aug. 27, 1910.

The reasons for this contrast are, in the main, perfectly obvious. There is in the first place a greater survival of the individualistic idea of life in the country than in the city. Government touches the life of the individual in the country to a limited degree only. His personal liberty, so called, is seldom invaded. He is, and he considers himself to be, a law unto himself. In the city the communal idea prevails; no man lives unto himself alone; government is at the elbow of every citizen. In the second place, the very isolation of the country makes it almost impossible in the circumstances to educate the country people in the importance of health measures. A single successful campaign against measles or diphtheria or impure milk will generally convince the people of the city of the importance of health measures. As such a campaign is difficult or impossible under present conditions in the country, education comes more slowly and the support of health measures is always more doubtful. In the third place, the contrast between country and city is largely due to the fact that health measures are more obviously necessary in the city than in the country. The crowded city demands health protection. Where our nearest neighbor lives half a mile away he may suffer from a wide variety of diseases and we may never feel the danger, but where we are separated from contagious disease only by the partition wall of an apartment house, we feel the necessity for and yield more readily to preventive measures.

The explanation for this contrast, however, is not its justification. The country no less than the city needs health education. The country, even more than the city, stands in need of fundamental health precautions. The very mass of disease in the country districts of itself requires that this problem be attacked, but the bearing of rural sanitation on the health of our cities is perhaps a still more immediate reason why our point of attack should be shifted. The health of the city depends in a large measure on the health of the country. Practically all the food products of the city come from more or less remote country districts. A single case of typhoid fever on a dairy farm may, under certain conditions, infect a whole city, and emphasize to all the intimacy of the sanitary connection. In the same way close intercourse between cities and the country renders the former particularly liable to infection from the latter. Experience in many places has convinced us that the prevention of smallpox in the cities is very largely dependent on the close inspection of smallpox in the country, since most cases of this disease are brought into the cities from rural districts or small towns. Then, again, there is a crying need for better rural sanitation because of the more or less general residence of city people in the country during vacation time. The country boarding house has been one of the great sources of typhoid fever, and many of the cases which appear in the cities

after vacation can be traced directly to the bad sanitation of country resorts. If, therefore, the health of the cities is to be improved the health of the country must also be bettered. And if the nation is ever to stamp out disease it must be by a general attack in both the city and the country.

In addition to the crying need for such work rural conditions offer to the scientific sanitarian the attraction of almost unparalleled opportunities for research work in the transmission of disease. In typhoid fever, particularly, the key to the eradication of summer typhoid is to be found in the country. To trace the means of dissemination of typhoid bacilli in a city, with its manifold sources of food supply, the complication of the milk supply, with daily contact between thousands of persons, any one of whom may be in the incubative stage of the disease or may be a typhoid carrier, and with the constant temptation to attribute the infection to the water supply, is beset with so many difficulties as to make it almost hopeless. The best that can be done is to draw general conclusions from the study of large groups of cases, and even here it is difficult to exclude the general factors of flies, milk, and water.

In the country conditions are very different. Given a country district free from typhoid for several years, the first case is easily discovered, and the transmission of the disease may often be worked out with mathematical accuracy. Water and milk are of course easily excluded; flies may be considered with some accurate idea as to their importance as a factor in transmission; and the actual amount of contact resulting in infection may often be determined exactly. If this work be extended over a largre area and be combined with careful statistical studies it will throw more light on the city problem than can be obtained in the city itself by any means known at present.

Nor is typhoid the only disease which can be advantageously studied in the country. We have found the study of the transmission of smallpox in rural districts to be of great interest by reason of the fact that the time, place, and manner of contact can be worked out with ease and certainty. Diphtheria and scarlet fever, studied case by case in rural districts, should throw great and much-needed light on the transmission of these diseases.

It may not be amiss at this point to call attention to the value of the case method of study of infectious diseases in rural work. A personal visit to each patient, the collection of the data needed at the place where the disease occurred, and the interpretation of the epidemiologic evidence in the light of the other information secured by a visit to the premises, offers by far the most promising method for the solution of the problems now pressing for solution.

The rural districts, however, offer even greater possibilities in practical prevention than as a field for studies in the transmission of

disease. The separation of individual cases, the slowness and freedom from complication of the intercommunication, render health work in the country much easier than in cities. With trained men and an adequate system for promptly collecting and studying morbidity statistics, preventive work in rural districts may be made to have the efficiency of a well-oiled machine.

Even here, however, it is obvious that all the phases of sanitation which arise in the study of rural conditions can not be studied fully by the limited force at the disposal of the average state health department. Some limitations must be made and some problems in the country must receive more attention than others. We have carefully considered the subject and have concluded that, for the present at least, particularly in the South, typhoid fever and hookworm diseases should receive first attention. The reason for this decision will, I think, be obvious to all. Typhoid fever is and will probably remain the greatest single problem of rural hygiene. High as is the death rate from typhoid fever in the country as a whole, it is highest in the South; and awful as is the toll which most southern cities pay to this disease, their burden is not so heavy as that of the rural sections of the same territory. Hookworm has been placed beside typhoid fever in this work because we are convinced that hookworm plays a part hardly less important than that of typhoid fever in the South and is essentially a disease of the country.

If we must study rural hygiene for its own importance, and if we must limit our study for the present at least to these diseases which are the most disastrous, we must begin our study on the farm. We should not, of course, omit the small towns, as they offer problems intermediate between those of the city and those of the country. But a study of these towns convinces us that in the main the dangers are essentially those of the farm, and the problem is practically the same in its fundamental aspect as that to be encountered in the country.

The farm is the point of attack, and in the work against the diseases I have mentioned the farm is the unit both in the spread and prevention of infection. Each farm is, to all intents and purposes, a separate community, with its own population, its own problems of sanitation, and its own forces for good and evil. The work we would do for the improvement of rural conditions of sanitation must be done for the improvement of the farm.

Studies of sanitary conditions on farms show facts that are almost unbelievable in the light of our knowledge regarding soil pollution. We have inspected in the course of our work against typhoid and hookworm diseases thousands of farms, and it is the exception rather than the rule that we find adequate sanitary arrangements in use.

Wells are often carelessly dug, carelessly protected, if protected at all, and carelessly kept. The well tops, almost without exception, show wide cracks through which filth is washed at all times into the

well; the buckets are handled by all kinds of hands and then carefully lowered into the well for the only cleaning they ever get. The personal habits of the average inhabitant of a rural distict are of a character in keeping with the other sanitary conditions. The absence of running water, and particularly hot water, make effectual cleanliness, especially in cold weather, difficult, and the amount of water used per capita per day is exceedingly small.

It must, of course, be admitted that in every rural community there are those of sufficient intelligence, self-respect, and ability to rise above these conditions and to provide themselves with modern sanitary conveniences, but, particularly in regions where the economic standard of rural life is low, these exceptions are few, and for the most part conditions are as I have described them.

Even under these conditions, amazing as it may seem, there are many rural communities which are and have been for many years practically free from typhoid, despite the prevalence of the disease in this country. There are others in which hookworm has apparently never gained a foothold, but the introduction of a single case of typhoid under favorable conditions is sufficient to give rise to a widespread outbreak of the disease, and hookworm infection, though slower in its spread, is equally certain to infect the entire community under these conditions.

These conditions, then, fix the problem of the farm, if they do not solve it, and indicate the direction our work must take. Proper sanitary conditions, the safeguarding of the water supply, and the instruction of the people as to the necessity of obeying the Scriptural injunction to wash before meat are not of themselves difficult, expensive, or revolutionay procedures. Moreover, when we take into account the fact that the carrying out of these procedures will do much to secure the immunity of the inhabitants of the farm from soil-pollution disease, it does not seem that it would be difficult to secure their adoption.

The problem must, of course, be attacked in detail, county by county, district by district, farm by farm, and individual by individual.

It has seemed to us that in attempting to solve this problem we could well take a leaf from the book of modern industrial enterprise; that the methods which have been worked out by the marvelous organizations of commercial interests might well be of use in a work of this kind. The problem of a man who would teach the people proper sanitation is not essentially different from the problem of the man who would sell them a book, or a safety razor, or induce them to buy an improved churn. The proposition is a selling proposition, and our forces may well be modeled on the sales force of any modern industrial enterprise.

The first question is that of advertising, or, as we are accustomed to speak of it, of education. At the outset it should be insisted on

that such health education or advertisement should be an education regarding the fundamental principles and established facts and not regarding individuals or experimental ideas. In our advertising campaign to reach the farmers we must suppress all personal references and make our advertising carry sound and proved facts of sanitation. We must advertise our product and not our sales manager.

The forms of publicity to be used in this educational campaign are varied, and practically all of them are to-day being used in common by commercial and health organizations. Press notices, which are easily secured at small cost by a proper press agent, are of enormous value. Special stories are gladly carried by newspapers if they do not carry too much self-advertisement; billboards, magazine stories, and articles, and special publications of various health departments are being used daily in this work. In addition, lectures, exhibits, special railroad exhibit cars, demonstrations in railway stations and public places, all have their place and all are being used by public health agencies.

But these are not of themselves sufficient. They arouse the interest or excite the curiosity of those whom we wish to reach, but they do not give the individual the necessary impulse for immediate action. We must have something more personal, more direct and impelling, to obtain the results that are necessary. Here again the analogy with selling forces of commercial concerns becomes striking.

We must have a detailed field force. We must have a force which will personally reach every farm whose sanitary condition we would improve. While all local health organizations have this end in view, and the individual physician constitutes a powerful force, even these must be aroused to their opportunities, must be educated and stimulated as much as our lay constituency. They correspond, in the analogy we have drawn, to the trade for the regular distribution of our product. We have not created the need for the product until our detail man has visited the consumer.

In practice the effort to meet the need for detail work, especially in connection with the hookworm, could be accomplished by the appointment of rural district inspectors. Each rural district inspector could be assigned to an area of four or five counties, conveniently located and accessible from some one point as headquarters. This district inspector would correspond to the detail man in our selling campaign. He goes into the district and visits first the physician, taking with him his microscope, his literature, and a small amount of properly prepared medicine. He should be a graduate physician, qualified to practice medicine, but his whole time should be devoted to the work and he should be allowed to accept no fees. On his visits to the individual physician he interests him in the hookworm disease, diagnoses a few cases for him, and treats several, in order to be sure that the physician is thoroughly acquainted with the practical details

of the work he is going to be called on to do. Then, with the cooperation of the physician, working in the practice of one physician at a time, he visits the individual farm, talks with the head of the family, or better still, with the mother, points out the children who are probably infected, gets specimens, leaves literature, suggests treatment, and refers them to the family physician. In this way, within a comparatively short time, he would cover the territory of the physician with whom he is working, secure a few object lessons of treatment, prepare the physician to take care of the cases when they come, and would thus start the current toward the physician. He also inspects schools, gives public lectures and demonstrations, and in general agitates the question until every one in the community is thoroughly acquainted with the facts regarding the disease.

This detail work so far has been very successful in some States. The patients who are treated recover so rapidly and exhibit such marked improvement as to constitute an unanswerable argument for the truth of the contentions of inspector and physician as to the importance of the disease.

The whole community rapidly becomes interested in the subject; the worst cases are soon treated and the mild cases come later; and with the spread of the truth regarding the prevalence of the disease and methods of its spread comes the desire for better sanitary conditions.

The amount of territory which can be covered by an active man in this way is very large, and, though we have not exactly determined it, we estimate that four or five badly infected counties can be cleaned up in a year's time, and that then the inspector may be moved to a fresh district. In this way four or five years should see a State thoroughly canvassed for hookworm disease, and the extermination of the disease should be in the way of accomplishment.

The work in connection with the hookworm will undoubtedly yield an extra result in typhoid fever equal in value to that from hookworm, and we believe that the successful carrying forward of the present campaign will result in a marked reduction in rural typhoid. In addition—and by no means least important—the demonstration of the practical benefits of systematic and scientific work in rural districts afforded by a successful campaign of this character will place preventive work on a new and firm basis before the country people and should render the systematic and permanent extension of this work, embracing all diseases, easy of accomplishment.

We believe, therefore, in conclusion, that present rural sanitary conditions must not be allowed to continue; that the problem must be attacked in detail; that detail work will yield tremendous benefits both in contribution to our present knowledge regarding the transmission of many diseases and in the actual prevention of thousands of unnecessary cases of preventable diseases.

EPIDEMIOLOGY OF TUBERCULOSIS.

By Robert Koch.

(A lecture given before the Academy of Sciences of Berlin at its session of Apr. 7, 1910.)[1]

Investigations into the epidemiology of tuberculosis have brought out some facts of interest and also of practical importance which will be the subject of the present paper.

First some preliminary remarks concerning the character of the investigations. They are in all essential respects statistical. If attempt had been made to cover the entire field, insurmountable difficulties would have been encountered.

Tuberculosis, as is well known, manifests itself in the most varied ways, frequently occurring in such insignificant and latent forms that no sharp distinction can be made between those affected and healthy persons. For that reason it was necessary to limit the present discussion to a form that is sufficiently well marked and also diagnosed with certainty. These conditions are best fulfilled by tuberculosis of the lungs, the so-called pulmonary consumption. This form is also to be recommended for such investigations because it is by far the most frequent, the one chiefly concerned in disseminating tuberculosis and therefore the most important in medical practice.

A still further limitation must be made. Owing to the long duration of pulmonary consumption and the difficulty of making sharp distinctions as to its beginning, we must disregard the statistics of illness from this disease and consider only the statistics of death. In these we have original data that are, to a certain extent, trustworthy, and that may serve as a basis for investigation.

It is true that this trustworthiness could only be absolutely assured if in every case of death by pulmonary consumption the diagnosis were confirmed by an autopsy made by a competent expert,

[1] According to a manuscript kindly placed at the disposal of the editor of the Zeitschrift für Hygiene und Infections-krankheiten after the death of the author. Translated from Zeitschrift für Hygiene, Leipzig, 1910, vol. 67, Part 1, pp. 1–18.

which by no means really occurs. Autopsies are held only in a small proportion of cases, and therefore some uncertainty exists. Besides this, in many regions, even in entire countries, there is, for well-recognized reasons, a certain hesitation attached to pronouncing a diagnosis of pulmonary consumption, and the disease is called instead chronic catarrh of the lungs, or something similar. It is, therefore, not always admissible to compare with each other the death rates of pulmonary consumption of different countries without further examination, and it is to be supposed that many cases of striking differences may be explained by circumstances of this kind. This source of error has, however, no essential influence when we consider the increase or decrease of mortality in the same country or city.

On the other hand, it may be said that pulmonary consumption is a very satisfactory subject for statistical investigation, because its characteristic symptoms make its diagnosis quite certain, even by the laity, so that for many matters where absolute exactitude is not required, data are available, even though not supported by medical authority or by autopsies.

If in an investigation of the epidemiology of tuberculosis we go back to early data concerning mortality from consumption, we find the disease mentioned in the oldest records.

In the writings of Hippocrates a very characteristic description of pulmonary consumption is given, and we may conclude from it with certainty that the physicians of that time were quite familiar with the symptoms of the disease. It is stated in several places that numerous persons have been affected by it.[1] We must therefore conclude that phthisis already at that time played a part similar to that which it assumes at the present day.

We find the first numerical data, however, much later, and these relate to Sweden, where they were collected by the clergy.

From these we obtain the highest figures which mortality from phthisis has hitherto reached (Table 1). About the middle of the eighteenth century the mortality in Sweden was, for the country, 21.5 per 10,000 persons, and it rose very slowly to 27.7 about 1830.

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[1] From the writings of Hippocrates (Grimm's translation). On Epidemics, p. 16: "For consumption alone, as the most important single disease among those prevailing at that time, killed many people"; p. 57: "The greatest and most terrible disease, and the one which was the most fatal, was pulmonary consumption."

TABLE 1.—*Mortality from pulmonary consumption.*

[After Sundbarg. Calculated for every 10,000 persons.]

	In Sweden.	In Stockholm.
1751–1760	21.5	73.2
1761–1770	20.6	69.8
1771–1780	20.8	74.4
1781–1790	23.1	87.7
1791–1800	24.0	85.0
1801–1810	25.1	83.7
1811–1820	26.9	87.2
1821–1830	27.7	93.1
1831–1860	([a])	([a])
1861–1870	30.6	43.3
1871–1880	32.4	40.6
1881–1890	30.0	34.6
1891–1900	27.0	29.2

[a] No data given.

Considerably higher figures prevail in the chief city of the country, and this corresponds to the usually accepted opinion that the cities, on account of the crowded buildings and the bad dwelling conditions connected therewith and also because of the less resisting power of their inhabitants, are more unfavorably situated as regards tuberculosis than is the open country. Stockholm had in 1750 a mortality of 73.2, which in 1830 had advanced to 93.1; that is to say, nearly 100 per 10,000, or 1 per cent.

The increase of mortality from phthisis in Stockholm is said by the Swedish physicians to be caused by the misuse of alcohol. The rate of 100 per 10,000 is only met with where the most unfavorable sanitary conditions are encountered, for example, in jails, at least in former times; and also among the perishing races of North American Indians where alcohol is also the principal cause of decay. According to the concurrent testimony of various travelers, the inhabitants of Greenland, compelled by the northern climate to live crowded together in their huts, thus greatly increasing the possibility of infection, suffer in an extraordinary degree from tuberculosis, reaching, it appears, even a higher figure than 100 per 10,000.

A death rate of 50 per 10,000 occurs rather frequently in the last quarter of the nineteenth century, especially in cities. I will cite as examples among the German cities: Düsseldorf, 55; Elberfeld, 59; Osnabrück, 52; Cologne, 50½; Munich, 50. Especially high figures occur in Austria-Hungary where there is 50 for Buda-Pesth; 58 for Presburg; 66 for Fiume; 72 for Vienna.

From these figures we have a gradual descent until we reach a total absence of mortality. In certain regions, as in central Africa, tuber-

culosis occurs only in quite isolated cases, the patients being of European or coast origin. At the present time the lowest figure for some regions in Australia is about 7 deaths per 10,000. But this figure is also reached in some sections of our own country, as for example, in the district of Osterode in the Province of Allenstein.

Such low death rates have only been observed during the last few years, and this leads me to the most notable phenomenon in the epidemiology of tuberculosis, to which I would especially invite your attention, namely, the almost universal marked decrease in pulmonary consumption which has become evident during the last 30 or 40 years.

The lowering of the death rate began first in England, and it also happened that the English hygienist Farr was the first who was struck by this and who called attention to it. In our own country Hirsch, the author of the well-known Handbook of Historico-geographical Pathology, was the first to mention it.

This remarkable phenomenon was at first received with great scepticism, and it was alleged that there were either errors in the statistics or that it depended upon the decrease in the general death rate which had been previously noted, though not to the same degree. But as the decrease in pulmonary consumption was shown to occur almost universally and also continued, there remained nothing to do but to acknowledge it as a fact and to find an explanation therefor.

In order to give an idea of the decrease of consumption, the course of the death rate from that disease in the Kingdom of Prussia may serve as a specially characteristic example.

It is shown graphically by a curve in Table 2. Up to the year 1886 the figures representing the mortality remain with irregular, but not marked variations a little above 30, then begins a decrease which has kept up with but little variation to the present time. In the year 1908 the figure fell to 16.24, a decrease of nearly 50 per cent.

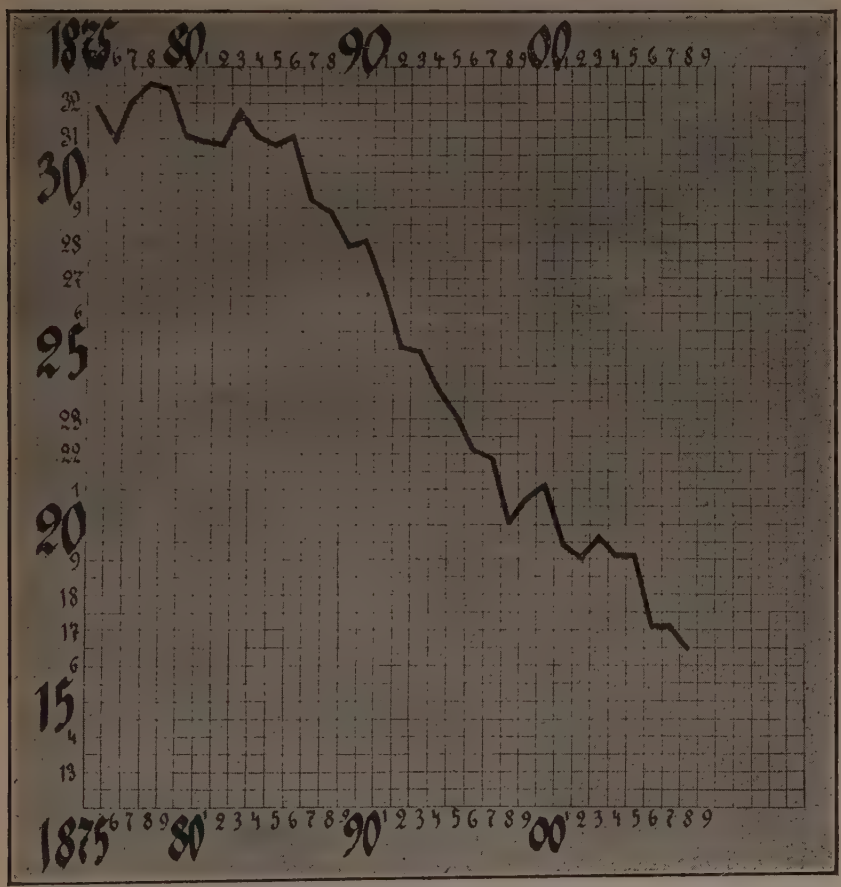
For the German Empire the statistical records do not go back far enough to demonstrate the reduction in consumption in a similar manner. Yet the curve for all Germany resembles, as far as it goes, that for Prussia; it is somewhat higher, because the States of southern Germany are not as favorably situated as Prussia with regard to the disease.

The significance of this reduction in consumption will be noted when we observe that if the same relations prevailed now as 30 years ago about 100,000 more persons would die annually of consumption than is now actually the case. It is therefore very important for us to ascertain the causes for this decrease, in order to know whether it is subject to any influence under our control; whether it would be possible, were it arrested, to overcome the obstacle, also whether it would be practicable to hasten its decline beyond the present rate.

The question, therefore, arises as to what is the cause, or rather what are the causes of this decrease, for it can hardly be supposed that it depends on a single factor alone.

Concerning this it might at first be supposed that the death rate from consumption decreases because the general death rate, as is well known, is also decreasing. This need not necessarily be so, for it would only occur in case the causes which influence the general death

TABLE 2.—*Mortality from consumption in Prussia.*



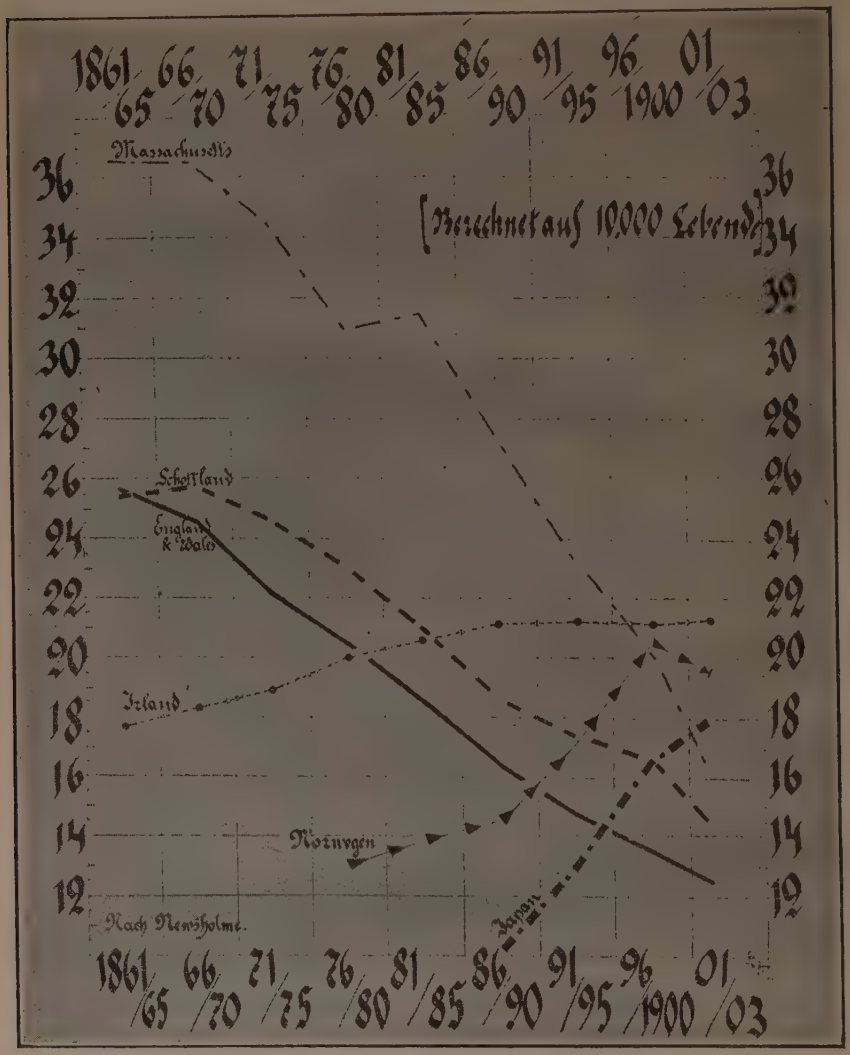
rate have a similar influence upon the death rate from consumption. But we now see that the decrease in the latter is much more rapid than that of the general mortality, this being more probably influenced in a considerable degree by the decrease in pulmonary consumption. Therefore that disorder must be influenced by factors peculiar to itself.

It might also appear possible that the decrease in tuberculosis depends upon the general epidemiological course of this disease; that

this epidemic in itself, like other epidemics, such as the plague and cholera, must decrease after a certain lapse of time.

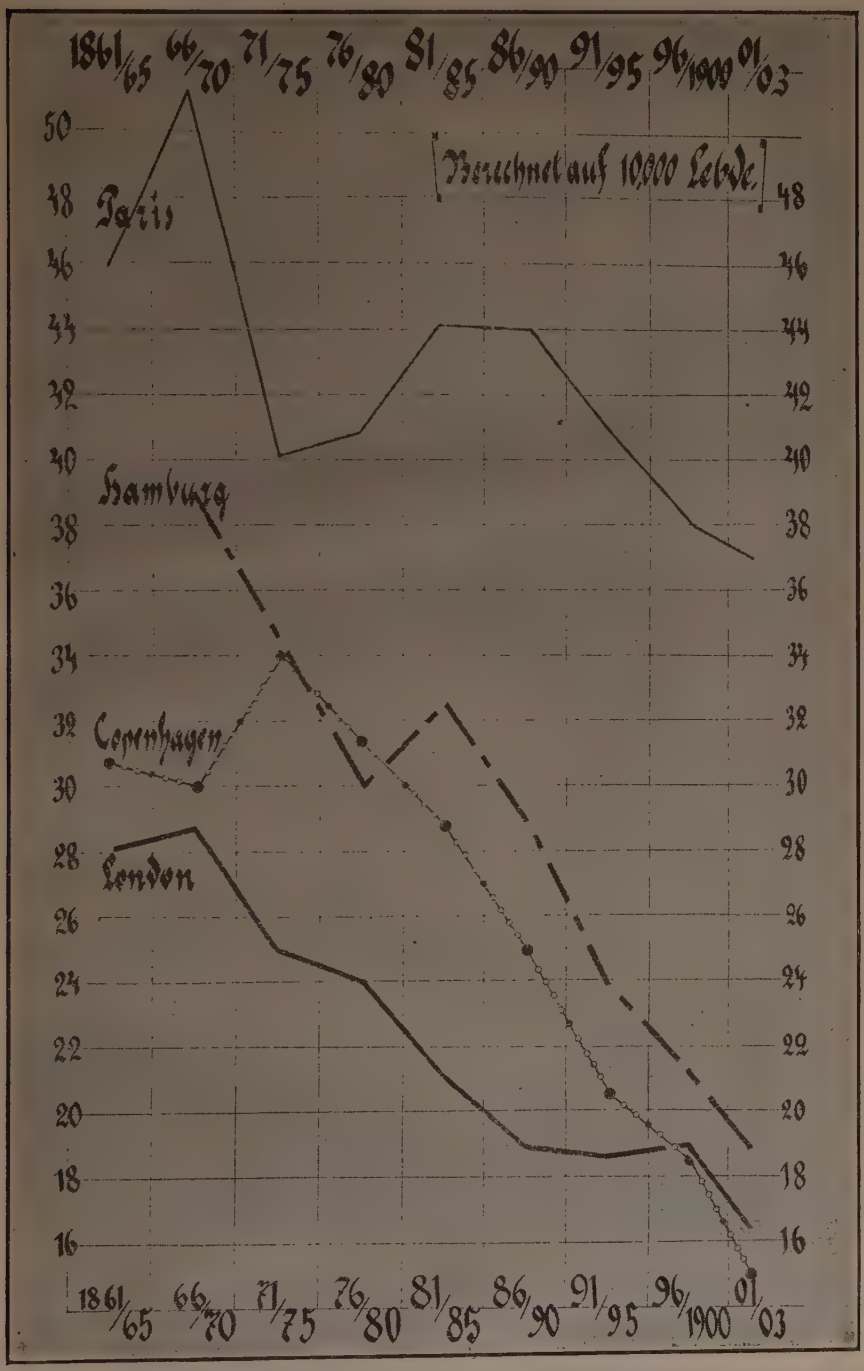
If this were its natural course then the decrease would proceed everywhere in a uniform manner. But this is by no means the case.

TABLE 3.—*Mortality from consumption in Massachusetts, Japan, Great Britain, and Norway.*



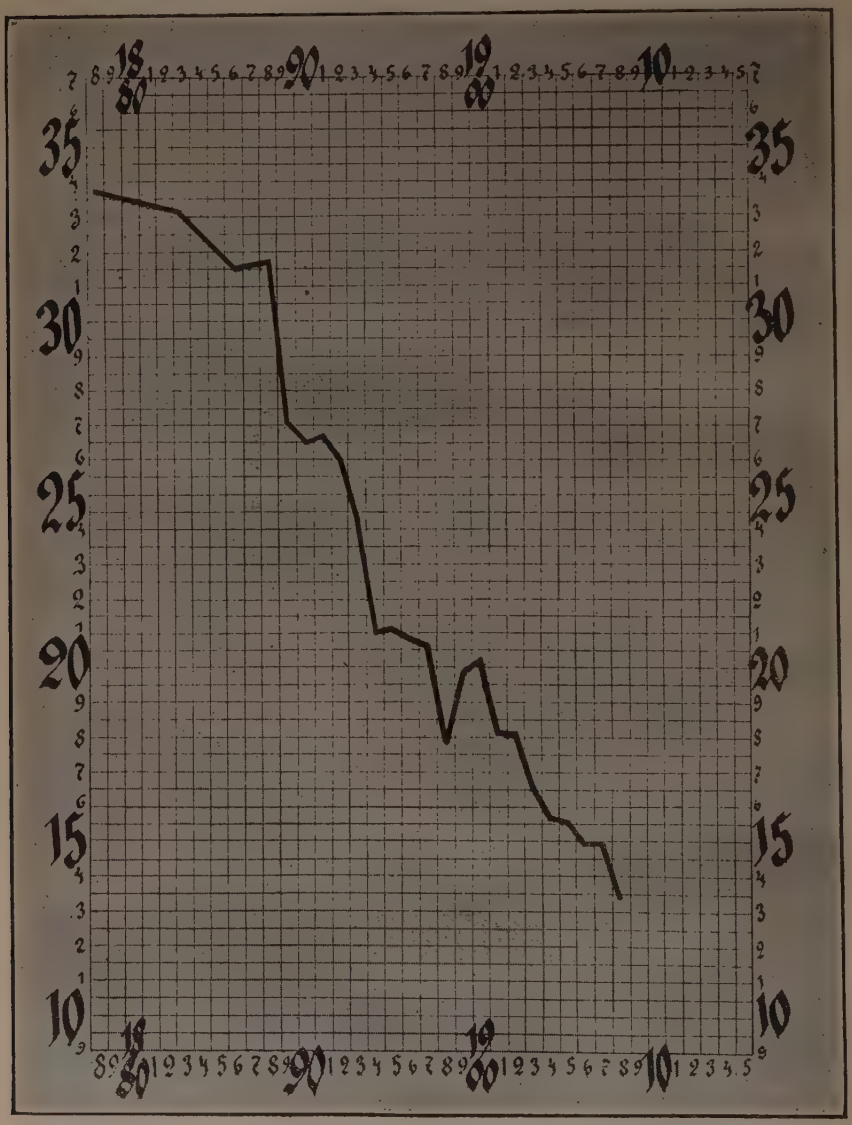
In most countries, it is true, the curve descends, but there are others in which it rises. It will be seen by consulting Table 3 that England, Scotland, and the American State of Massachusetts (chosen because its statistics reach far enough back) have a decreasing death rate from consumption, while in Ireland, Norway, and Japan it is increas-

TABLE 4.—*Mortality from consumption at Paris, Hamburg, Copenhagen, and London.*



ing. We meet with the same phenomenon in certain cities; so London, Copenhagen, and Hamburg have curves of decrease, while Paris, on the contrary, has a high-lying curve which shows but little tendency to descend (Table 4).

TABLE 5.—*Mortality from consumption at Hamburg.*



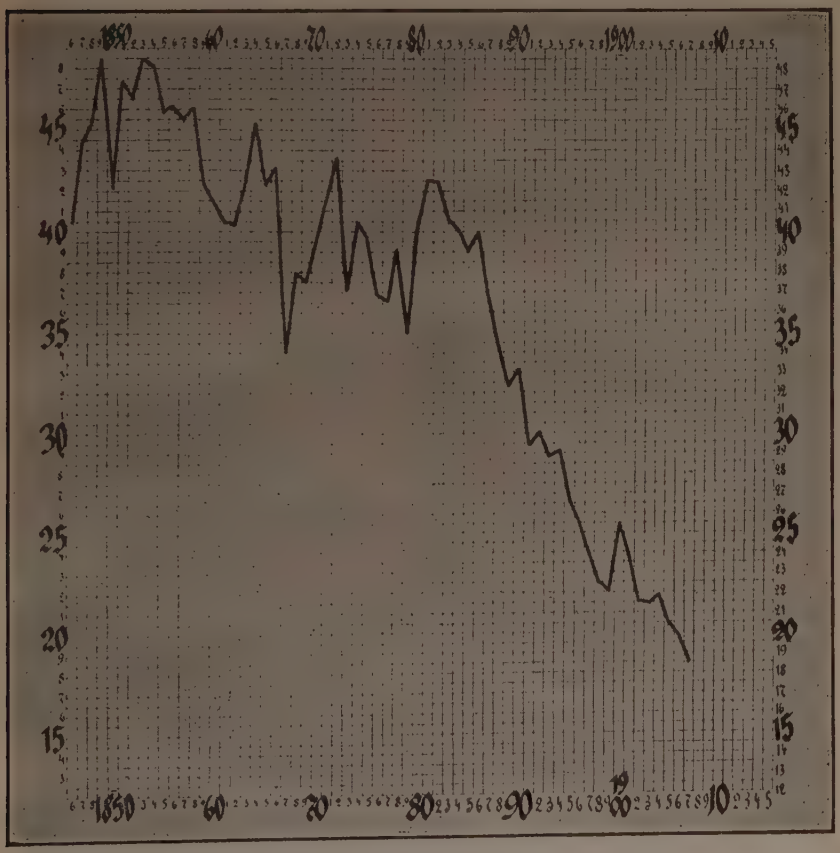
France has a death rate from consumption that is especially unfavorable. In cities of more than 5,000 inhabitants, the only ones for which statistics are available, 27 out of every 10,000 persons die of this disease, and there was no decrease in the years from 1901 to 1906 (so far as the data have been published).

Very characteristic examples of favorable indications in the mortality of consumption are shown by Hamburg (Table 5) and Boston (Table 6).

Before 1860 Hamburg lost by consumption 37 for every 10,000 inhabitants, and in 1880 the figure stood at 33.5. In 1907 the mortality had decreased to 13.7.

Boston had in 1886 a mortality of about 40, in 1907 it was 18.5.

TABLE 6.—*Mortality from consumption at Boston.*



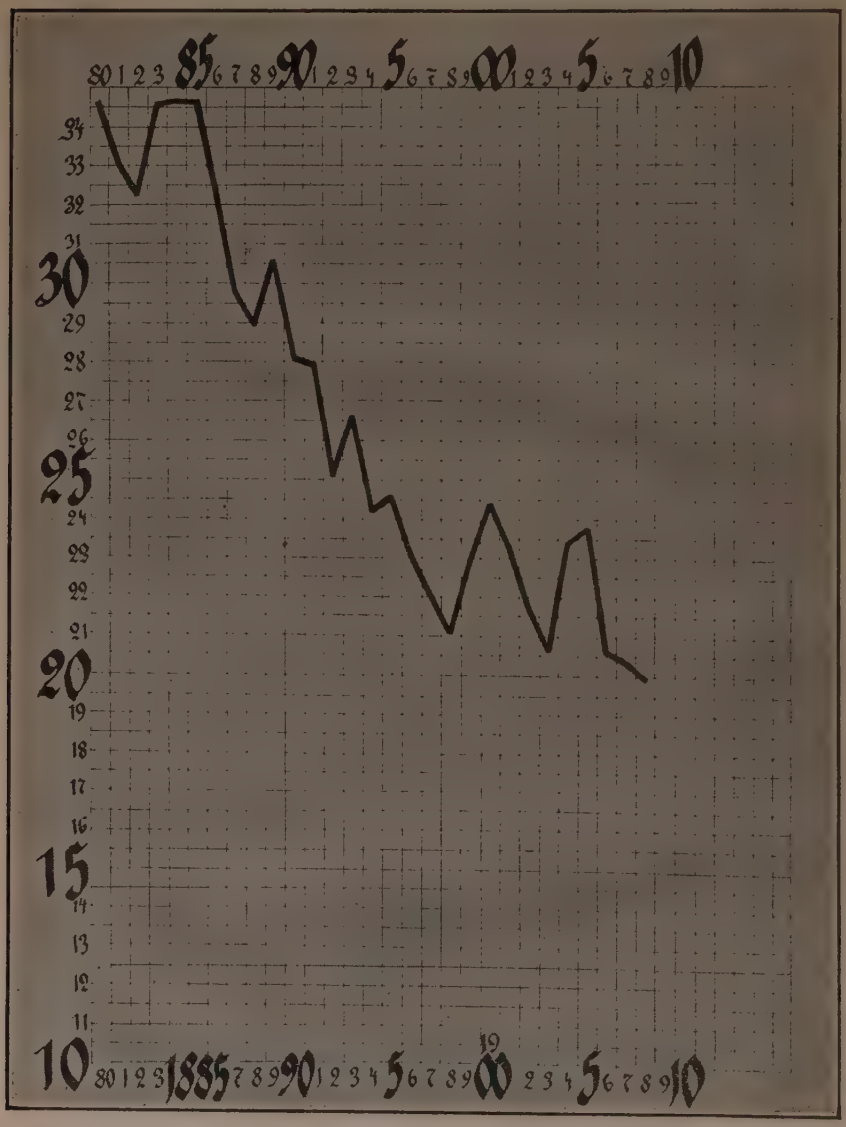
These figures are still more significant if we compare them with those of cities which are exposed to conditions similar to those of Hamburg and Boston. For this purpose we will compare Hamburg with Berlin (Table 7) and Boston with New York (Table 8).

The mortality curves of Hamburg and Boston descend at once and the decrease continues at a uniform rate, while in New York and especially in Berlin it has slackened for several years past.

The examples I have submitted, and which might easily be increased in number, show that there can be no question of a general,

regular, uniform decrease in mortality from consumption, and that we must therefore seek for other factors than those dependent on a spontaneous cause of decrease connected with the epidemiological course of the disease.

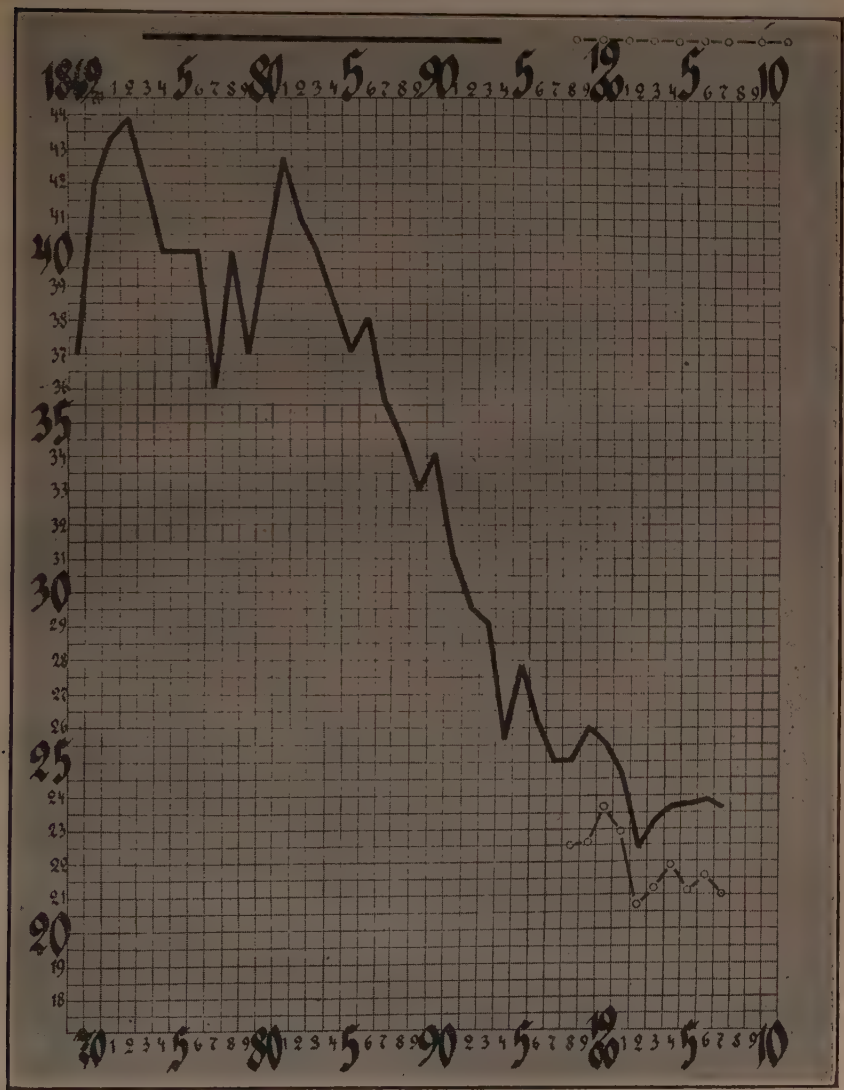
TABLE 7.—*Mortality from consumption at Berlin.*



It might be alleged that the virulence of tuberculosis has abated. But in reply to this it should be said first that the decrease in tuberculosis began quite suddenly, and after a few decenniums has reached, in many cases, 50 per cent and over. As the mortality from

consumption has been marked and often slowly increasing during 2,000 years it is not reasonable to suppose that it would decline all at once without any assignable cause. Besides, the decrease of virulence would first be manifested by an amelioration in single cases

TABLE 8.—*Mortality from consumption at New York.*



which would also more frequently terminate in recovery. But nothing of this kind occurs. It is indeed true that in modern times great advances have been made in the treatment of tuberculosis, and that we succeed, through the so-called hygienic-dietetic treatment and

especially by the specific treatment, in curing many cases. At present, however, only a comparatively small percentage of cases share this advantage, and for the cases not so treated we are unfortunately convinced again and again that pulmonary tuberculosis maintains the same deadly characters as formerly. Besides the decrease in consumption had already been going on for several years before the new methods of treatment had been widely disseminated.

The decrease in consumption has often been ascribed to the discovery of the tubercle bacillus. It has been said that by this, the infectious character of the disease was proved and that, in consequence of this, people became more cautious and avoided infection as much as possible, while previously physicians did not admit the infectiousness of consumption and the public at large followed them in this as a matter of course.

There is certainly much to be said for this argument. In any case it is very striking that, with a few exceptions, the decrease in consumption set in everywhere within a few years after that discovery. Yet the exceptions prove at once that this new-born fear of infection is not the only factor involved, although we must allow to it a certain influence which is by no means slight.

German authors have frequently claimed that social regulations, particularly insurance against illness, has had an effect upon the decrease of tuberculosis. To a certain extent this is undoubtedly true, particularly as regards present conditions in Germany; yet in most other countries, where such regulations have not yet been established, the decrease has been just as great and has been going on at the same time, so these regulations can not be with us the most weighty cause.

It would take me too long to enumerate and discuss all the attempts at explanation that have been made, and I will therefore confine myself in conclusion to those investigations of this question which appear to me to be of the most importance. These investigations were suggested by the striking fact that the death rate from tuberculosis shows great differences in the three countries belonging to Great Britain. In England and Scotland it is decreasing; in Ireland, on the contrary, it is slowly but evidently increasing. Newsholme, the well-known medical statistician, has endeavored to find the prime cause of this. With the greatest thoroughness he has examined all the factors in the question, chiefly lodging, food, conditions of service, care of the sick, emigration, and has finally become convinced that for Ireland the method of caring for the sick is the determining factor. While in England and Scotland phthisical charity patients are committed to isolated institutions, in Ireland they are supported without being required to place themselves in an institution; they therefore remain in their own lodgings and con-

tinue to spread infection about them. Newsholme endeavors also to prove that in Norway, too, the mortality from consumption is on the increase because insufficient care is taken for the placing of phthisical patients in hospitals. I might remark here that in Norway this defect has already been recognized and care has been taken to remedy it by founding special hospitals for consumptives. It appears that on account of this precaution the mortality curve in quite recent years no longer ascends. Newsholme says further that the very high mortality in Paris results from the insufficient hospital facilities, in consequence of which patients are not kept in long enough to insure protection of others against infection.

With reference to this I entirely agree with Newsholme that a commitment to hospital for as long a time and with as careful attention as possible is the most effective means of preventing infection and thereby the spread of consumption. My experience also shows that wherever consumptives are kept in sufficient numbers in hospitals there consumption is most diminished, and vice versa. It is also apparent that in no way can the danger of infection, which attends every phthisical patient, be so successfully combated as by isolation in a hospital. The value of hospital isolation is shown in a striking manner by such treatment of leprosy, as by its means we have attacked that disease with good results.

Besides this factor there is still a second one that plays a very important part. This is the housing of patients. The more contracted this is—the more lack there is of light and air—the more is infection favored. By many authors poverty and density of population have been mentioned as having a decided effect on the frequency of phthisis, and quite correctly so; but, in truth, this is caused by the defective and too small dwellings in which, through poverty and the increased density of population, people are forced to live. I might even go a step further and say that it is not so much the contracted character of the dwellings as a whole as the condition of the sleeping rooms that favors infection. Even in a spacious dwelling, in itself hygienic, the danger of infection may become very great if the inhabitants crowd together at night in a small sleeping room. It is certainly not an accident that with us the highest mortality from consumption is not found in the poor regions of the eastern provinces, but in the relatively prosperous and amply cultivated regions along the coast of the North Sea, where from olden times the evil custom has prevailed of using for sleeping rooms small, cell-like apartments built in the wall, the so-called cubbies (Butzen), which are shut up at night, and that in the northern parts of Sweden, with a climate that is notoriously healthy, the highest death rate for consumption occurs where people also sleep in closets quite similar to the cubbies of Frisia.

The striking fact that with us the cities often have a lower consumption death rate than does the surrounding country is apparently due partly to the want of hospitals and partly to the bad habits of the rural inhabitants, in that they, even when they have at their disposal several living rooms, select the meanest and smallest for a sleeping room. As an example of the distinction between city and country, the following statistics for certain Prussian provinces may serve (Table 9):

TABLE 9.—*Mortality from pulmonary consumption per 10,000 inhabitants.*

[After Hirsch, Historico-Geographic Pathology.]

Province.	In the city.	In the country.
Marienwerder	25.4	13.5
Danzig	23.9	14.1
Königsberg	24.9	15.5
Bromberg	31.3	18.5
Erfurt	26.9	27.0
Breslau	37.3	27.5
Hannover	33.8	44.4
Osnabrück	48.7	52.2
Cologne	47.6	53.4

But in cities, also, housing conditions are poor. There are numerous dwellings that consist of a single room, in which families, often with several children, live, cook, and sleep, often in a single bed. According to Rubner there are in Hamburg, Berlin, and Breslau 10 to 14 per cent of overcrowded dwellings, if we consider as such a room with but one window housing more than 5 persons.

Kayserling has estimated that, of the phthisical patients who die in their own rooms 40.6 per cent inhabit but one room, 41.7 per cent but two rooms; that in Berlin, during three years, 8,229 persons were exposed to the greatest danger of infection because of consumptives dying in one-room dwellings. It is well known that consumptives in the last stages of the disease, when they are helpless and expectorate sputum crowded with tubercle bacilli, are especially liable to spread infection.

If we adhere to the view that the most effective protection against infection is the isolation of consumptives in hospitals, and then reflect further that the number of such adult persons for which, on account of tuberculous disease, hospital treatment is necessary, amounts in the German Empire to from 150,000 to 200,000 annually, and that it is quite impossible to place these all in hospitals, nothing else remains but to isolate the greater part of them in their own dwellings. If it were possible to assign to each patient a separate sleeping room, this might be to some extent effected; but how can it be done if the entire dwelling consists of only a single room?

These considerations show that the decrease in consumption in recent times depends upon various factors, of which the two most important ones are the care of those affected by isolating them in hospitals and the improvement of housing conditions, especially as regards the sleeping rooms.

It is apparent from this that vast obstacles have yet to be overcome before we can succeed in reducing still lower the mortality from consumption, and finally reach a level which will possibly be below the lowest existing at the present time, namely, 7 per 10,000 persons.

We are now enabled to realize the great benefit that accrues from having an exact knowledge of the statistics of mortality from consumption in countries and cities. The mortality curve informs us at once whether the conditions are favorable or unfavorable, whether the mortality is decreasing and the measures taken are still effective, or whether improvements, supplementary regulations, etc., should be instituted. So in Norway the course of the consumption curve induced the authorities to take in hand the building of hospitals, and thus cause it to descend.

New York resolved, as soon as it was shown that the curve began to flatten and show greater variations, to take more care of the sick and to increase the number of beds assigned to consumptives from 2,500 to 5,000. In Berlin, for the same reason, there was erected a special hospital for pulmonary consumptives, with 1,000 beds.

It is very desirable that exact mortality statistics should be everywhere obtained and that studies of the same should be extended to smaller and smaller districts, so as to ascertain more fully the conditions that control the development of tuberculosis, especially in the case of small hamlets and country districts, and thereby to relieve them.

In our own country statistics are already developed far enough to enable us to scan the death rate from consumption in single districts. I have here the record of mortality in two departments, which exemplifies in a striking manner the interesting problems that result from a comparison between different districts. (Table 10.)

TABLE 10.—*Deaths from tuberculosis in 1907 per 10,000 inhabitants.*

Allenstein department (10.33):	
Osterode	7.2
Johannisburg	7.7
Sensburg	8.5
Neidenburg	9.5
Rossel	10.0
Ortelsburg	11.0
Lyck	11.5
Lötzen	11.5
Allenstein	13.0

Osnabrück department (23.34):

Osnabrück (country)	15.0
Iburg	17.0
Osnabrück (city)	18.0
Meppen	22.8
Melle	24.0
Aschendorf	24.0
Grafschaft Bentheim	25.75
Bersenbrück	28.0
Lingen	30.0
Wittlage	30.0
Hümmling	35.0

For an effective campaign against tuberculosis it would be necessary to go still further and divide each district into smaller areas, each of which should be specially investigated and provided with detention houses or other devices for combating the disease.

The statistics of mortality and the epidemiological researches connected therewith constitute an important feature of the measures by which tuberculosis is to be combated.

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